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(54) **WINDOW SOLAR HARVESTING MEANS**

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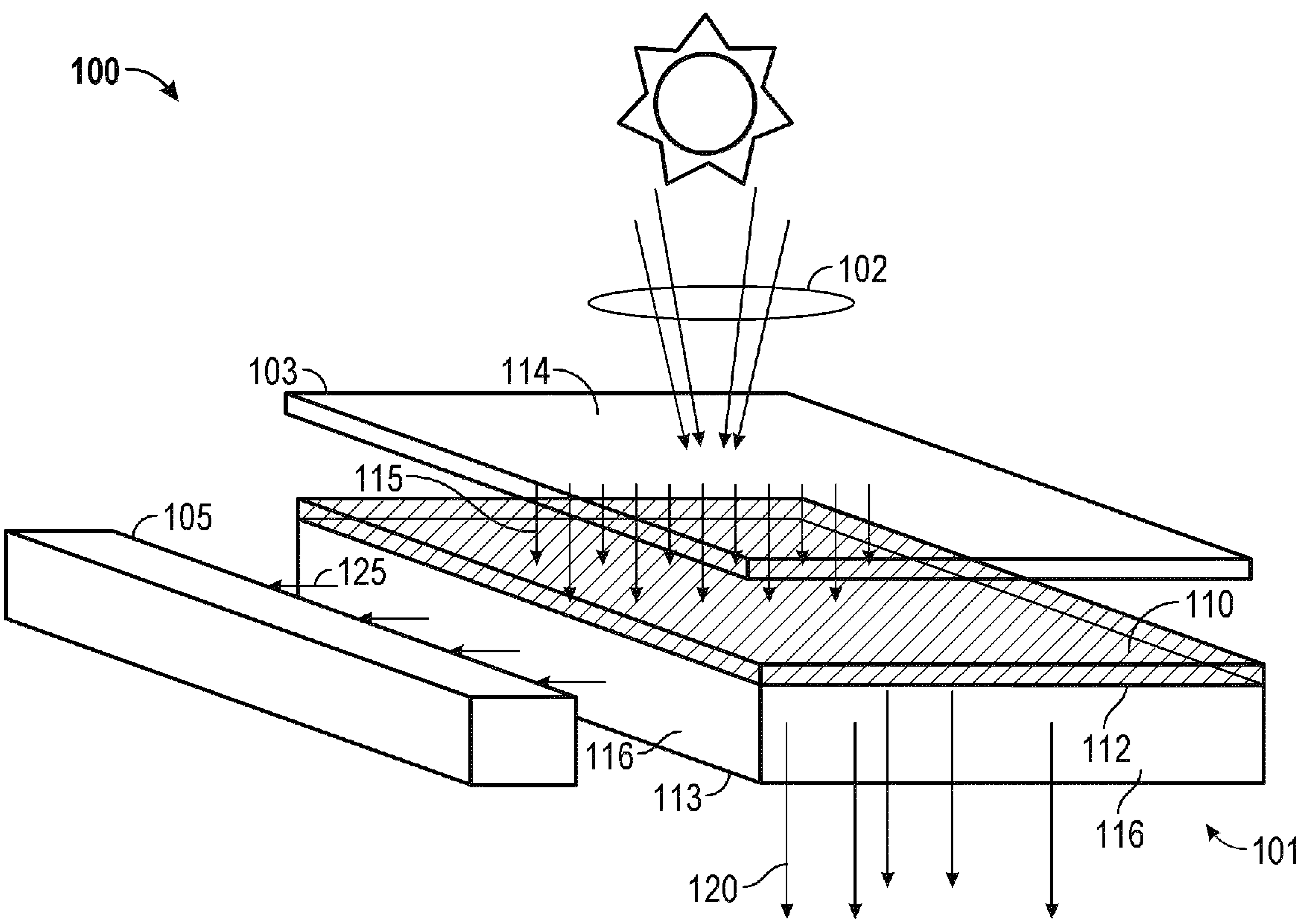
USPC **136/246**; 136/259; 29/428

(57) **ABSTRACT**

Systems, methods and apparatus are disclosed, including a light collector having a plurality of focusing elements and a plurality of light redirecting features that is optically coupled to one or more photovoltaic (PV) cells. In one aspect, the light collector includes half-cylinder shaped lenses that can focus light incident at various angles onto an elongate v-groove in the light guide such that a first portion of the incident light is diverted to one or more PV cells and a second portion of the incident light is transmitted through the light collector to provide illumination.



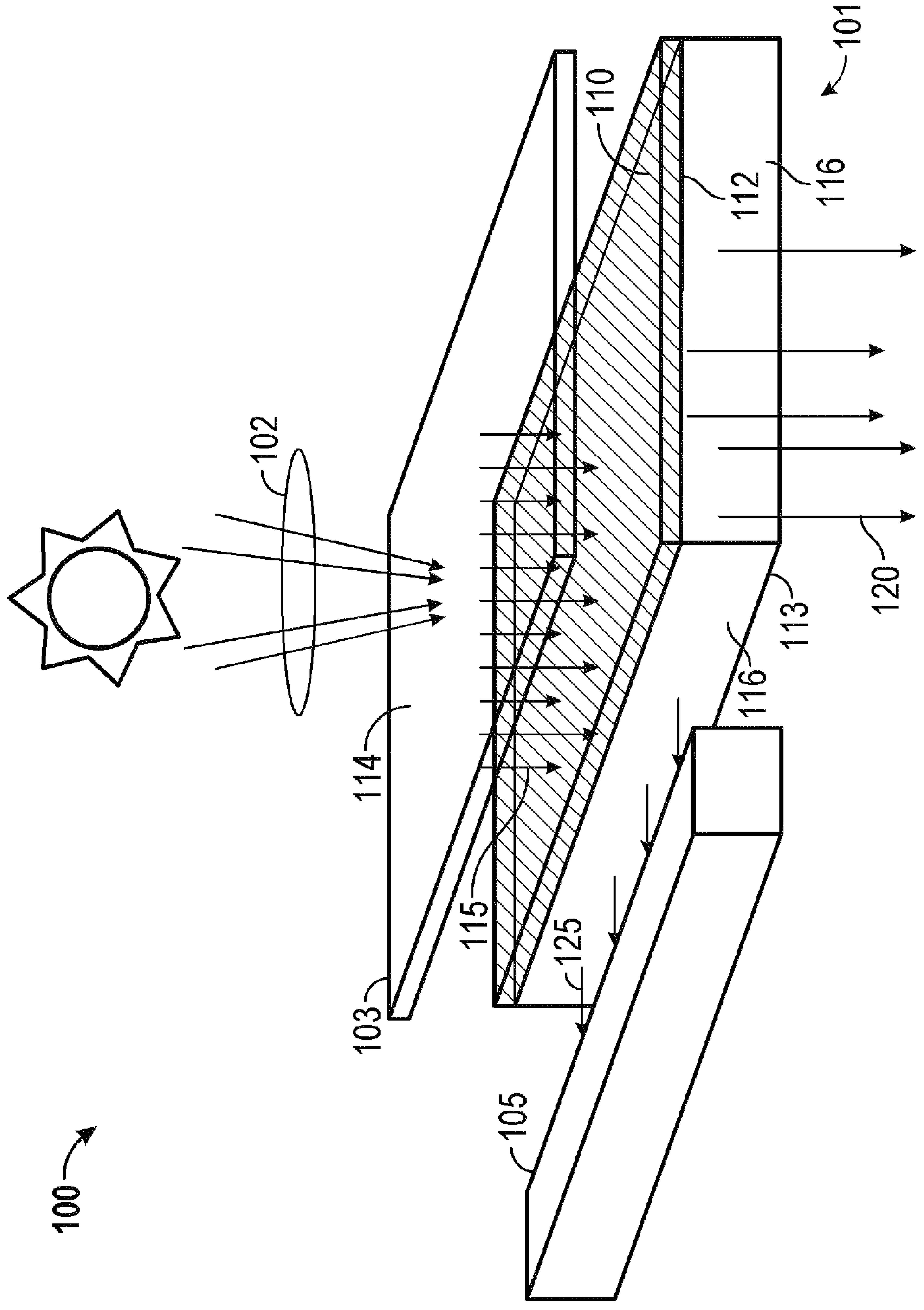


FIG. 1

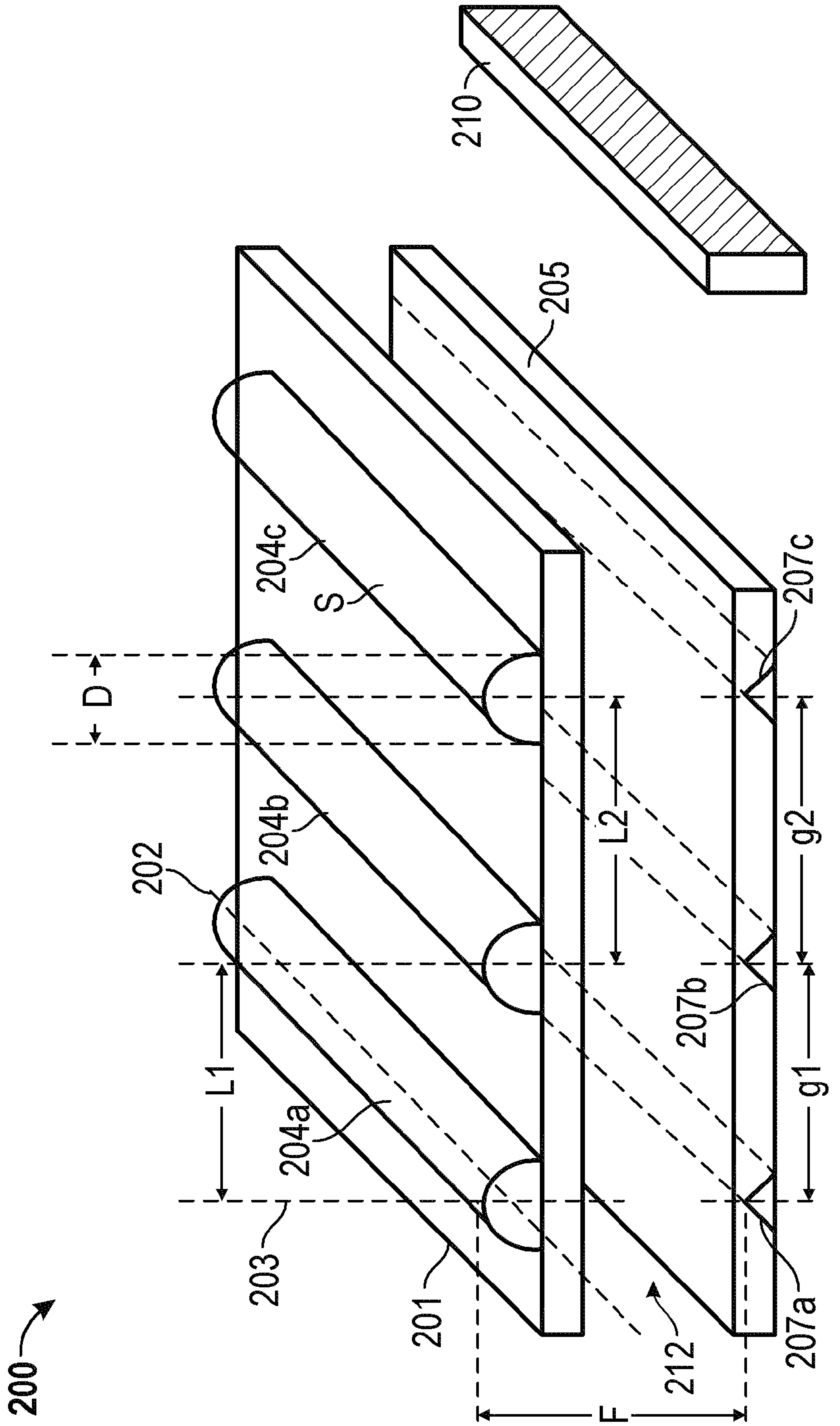

200
201
202
203
204a
204b
204c
S
D
L1
L2
205
207a
207b
207c
g1
g2
210
212
F

FIG. 2A

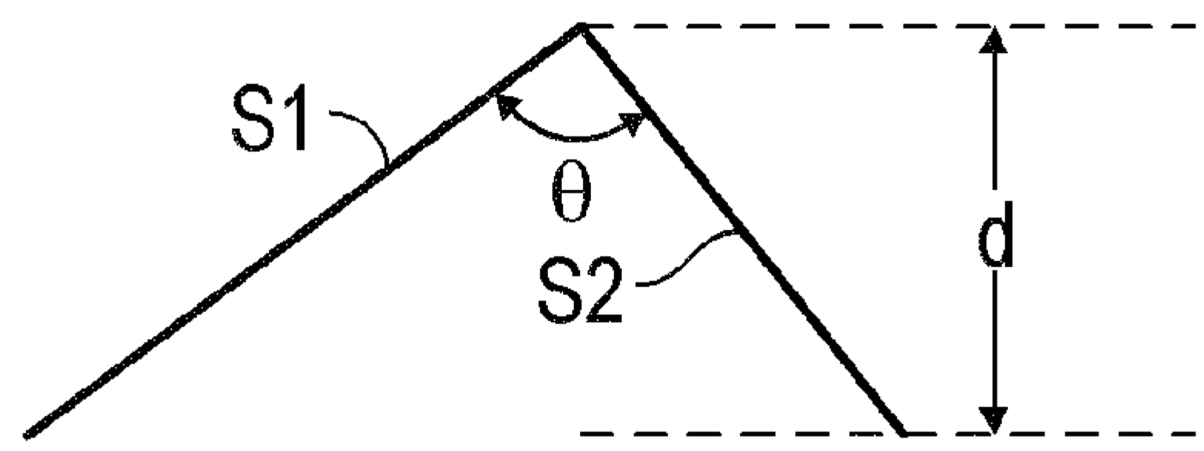

S1
θ
S2
d

FIG. 2B

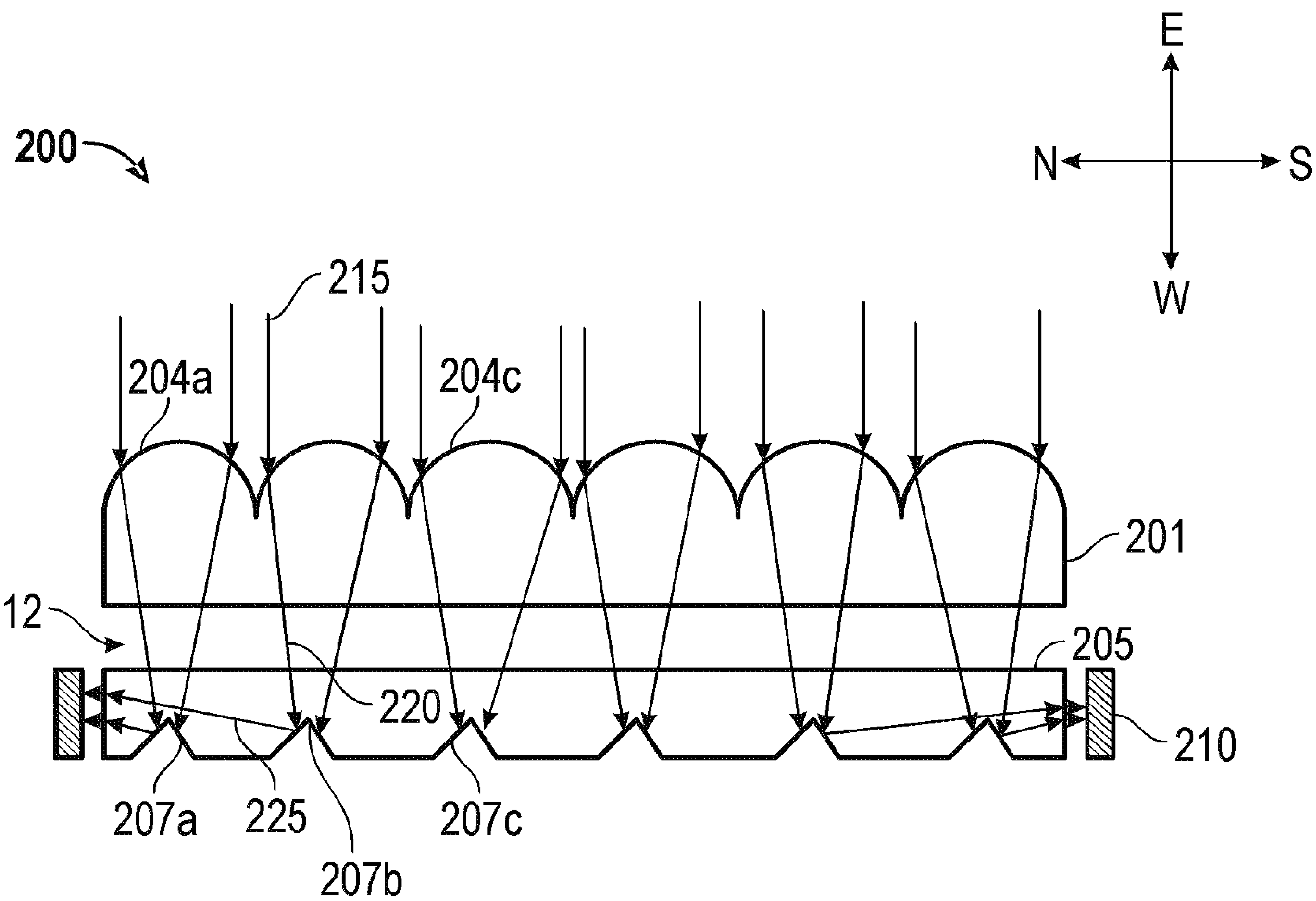

200
E
N
S
W
215
204a
204c
201
212
205
220
210
207a
225
207b
207c

FIG. 2C

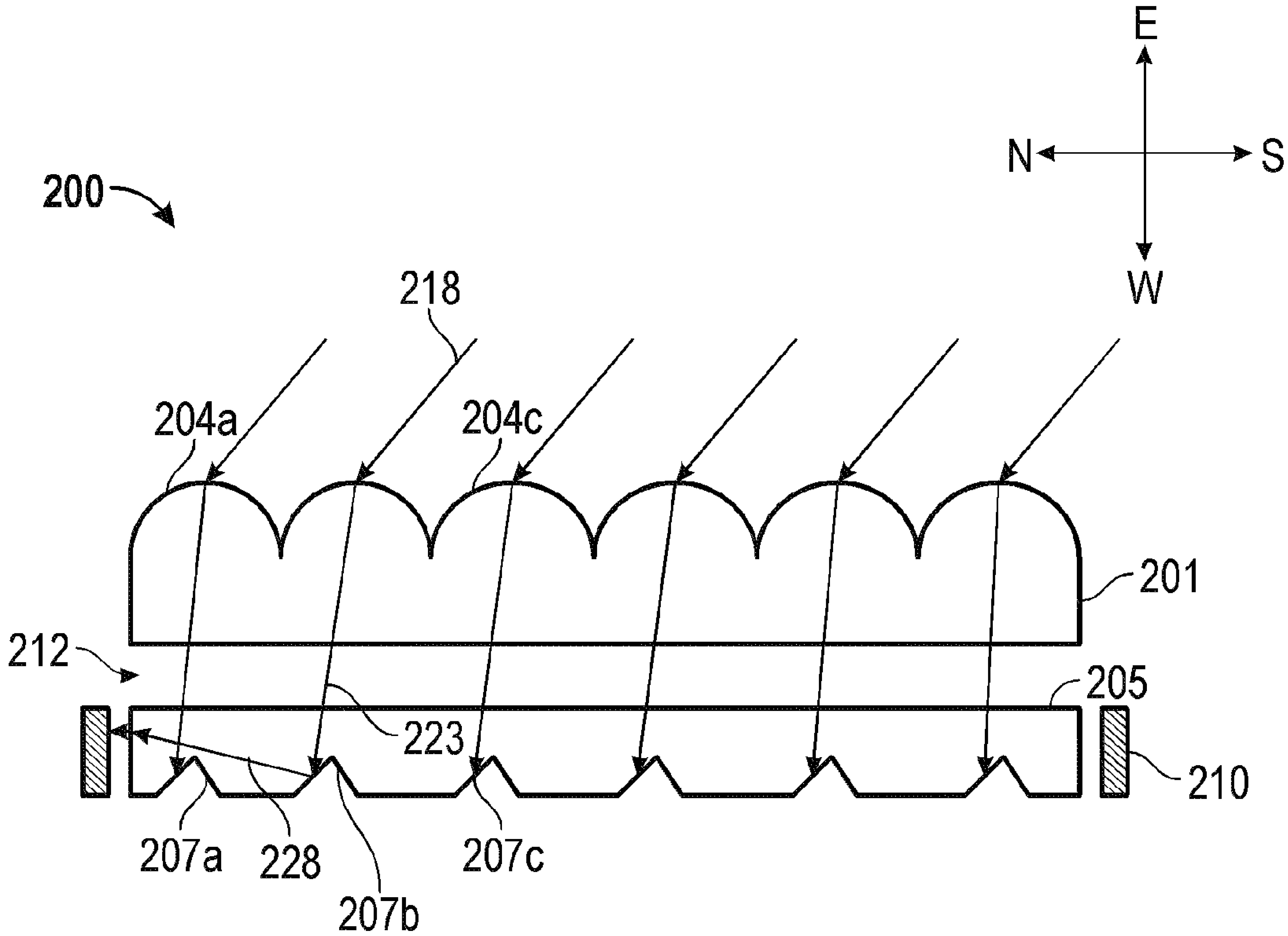

200
E
N
S
W
218
204a
204c
201
212
205
223
210
207a
228
207c
207b

FIG. 2D

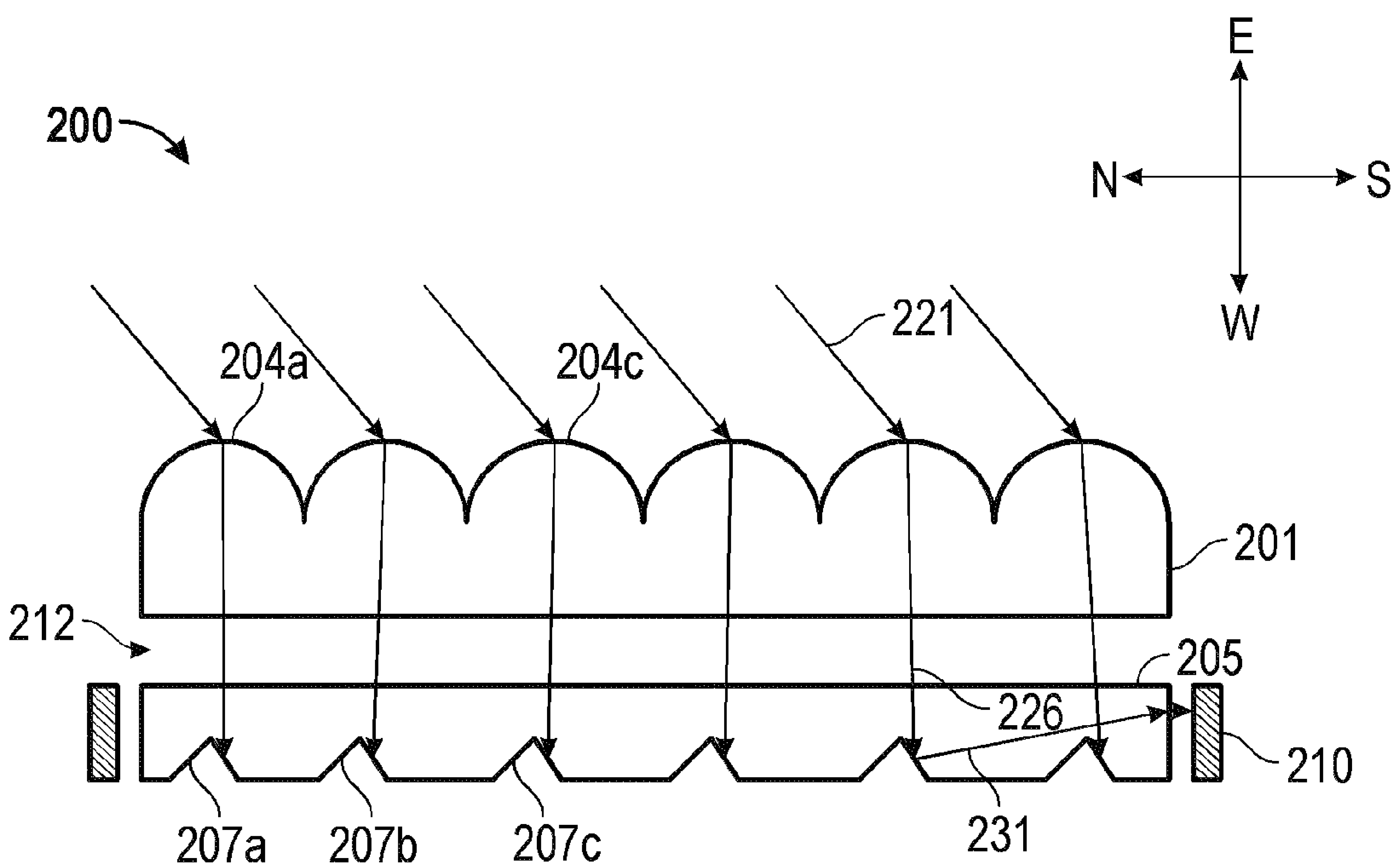

200
E
N
S
W
221
204a
204c
201
212
205
226
210
207a
207b
207c
231

FIG. 2E

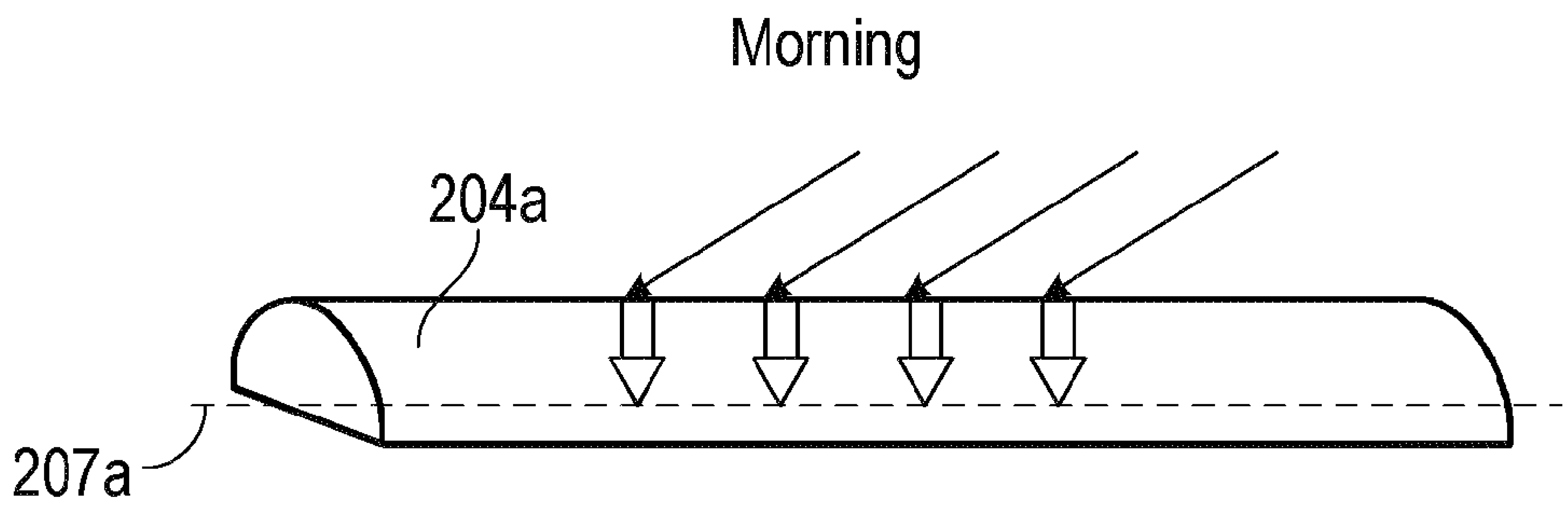


FIG. 3A

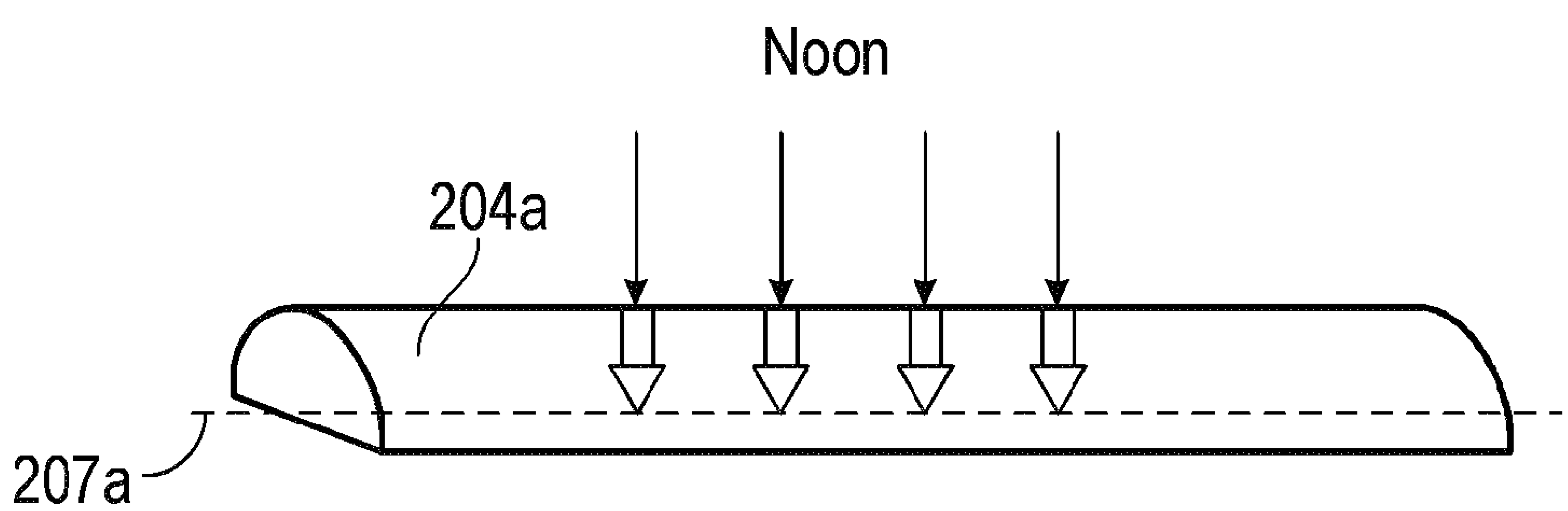


FIG. 3B

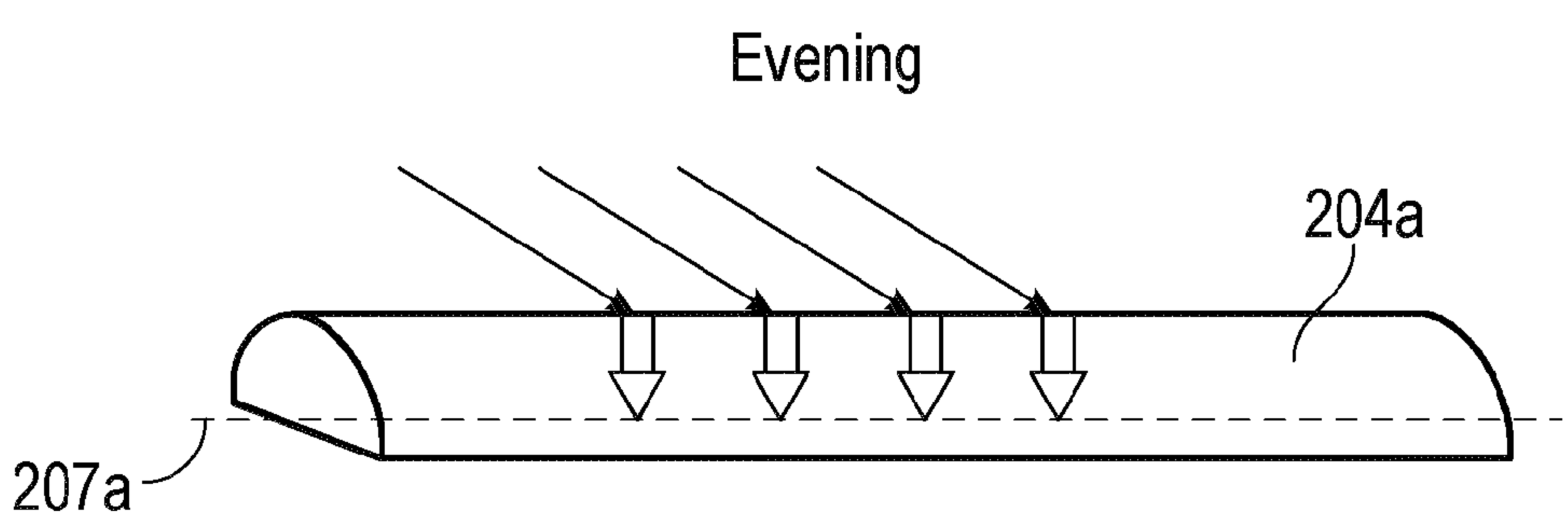


FIG. 3C

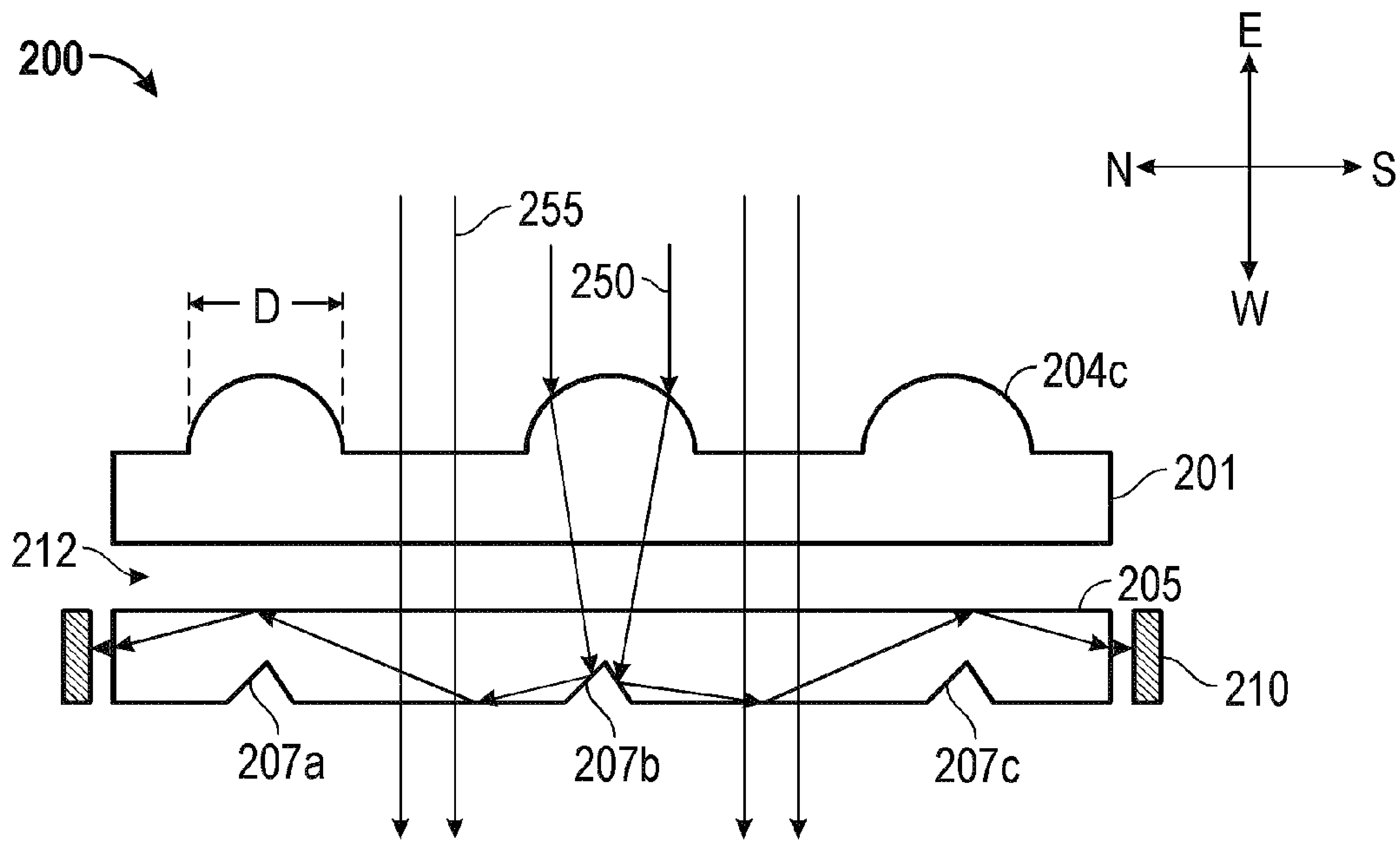

200
E
N
S
W
255
250
D
204c
201
212
205
210
207a
207b
207c

FIG. 4A

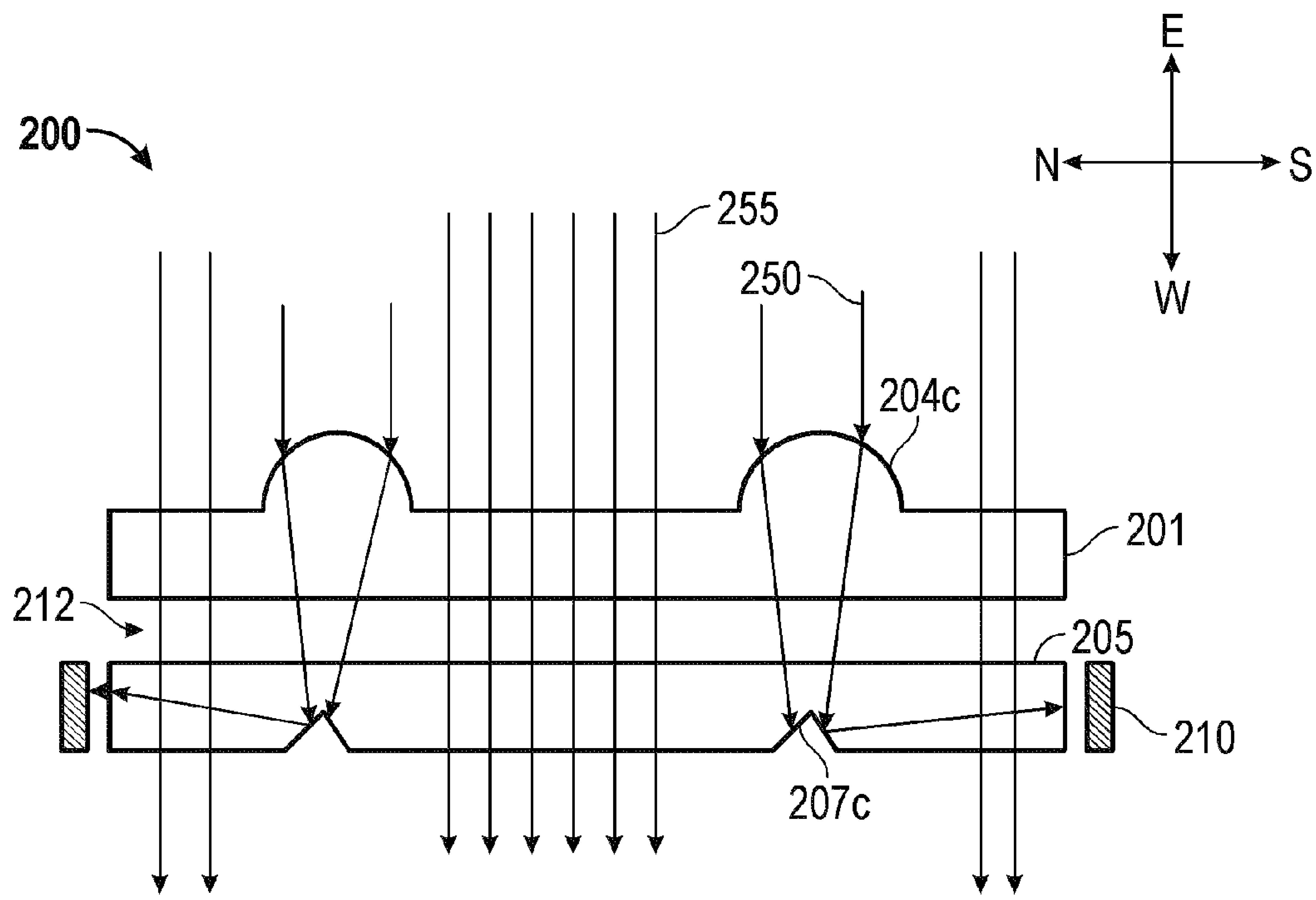

200
E
N
S
W
255
250
204c
201
212
205
210
207c

FIG. 4B

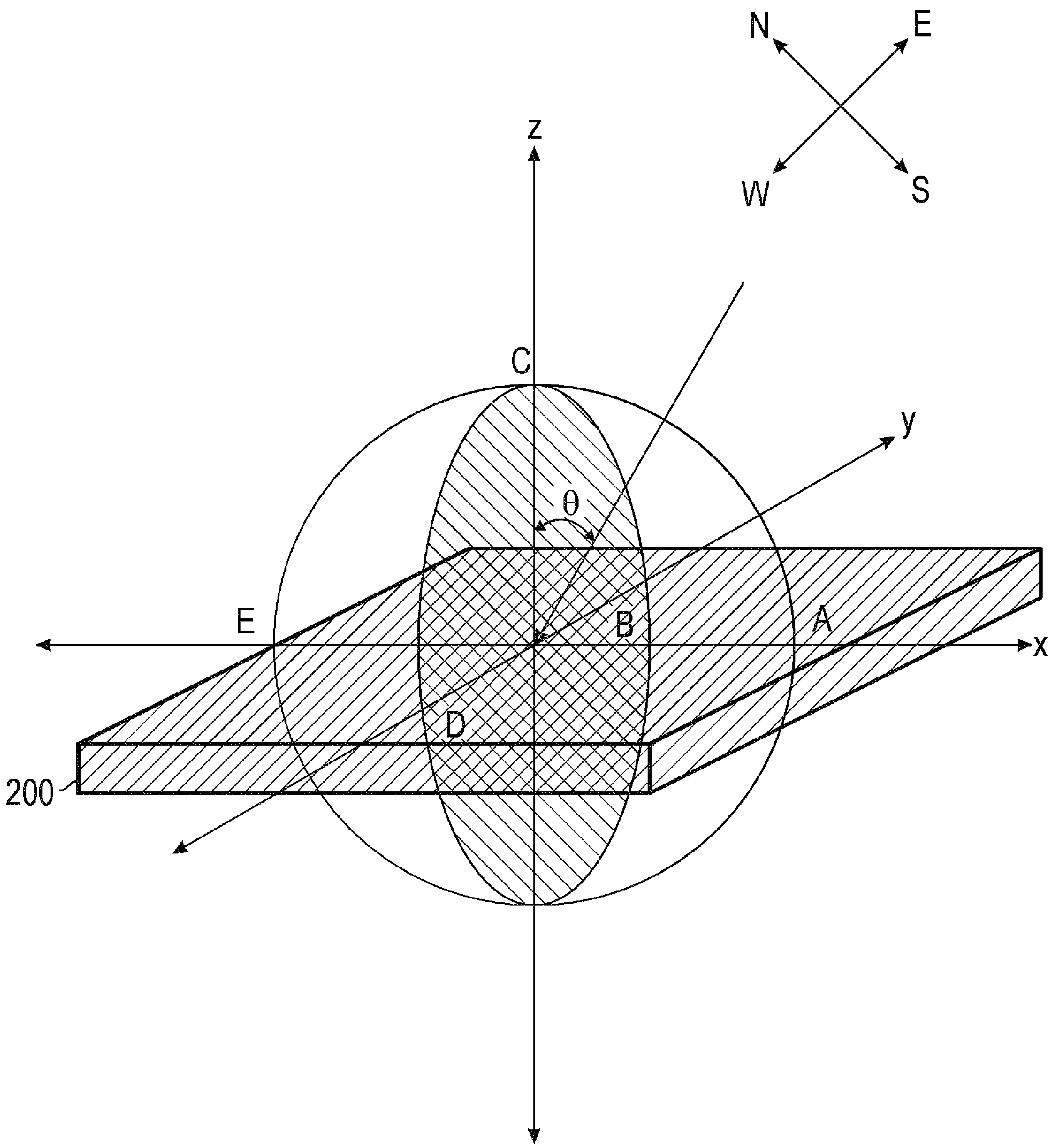


FIG. 5A

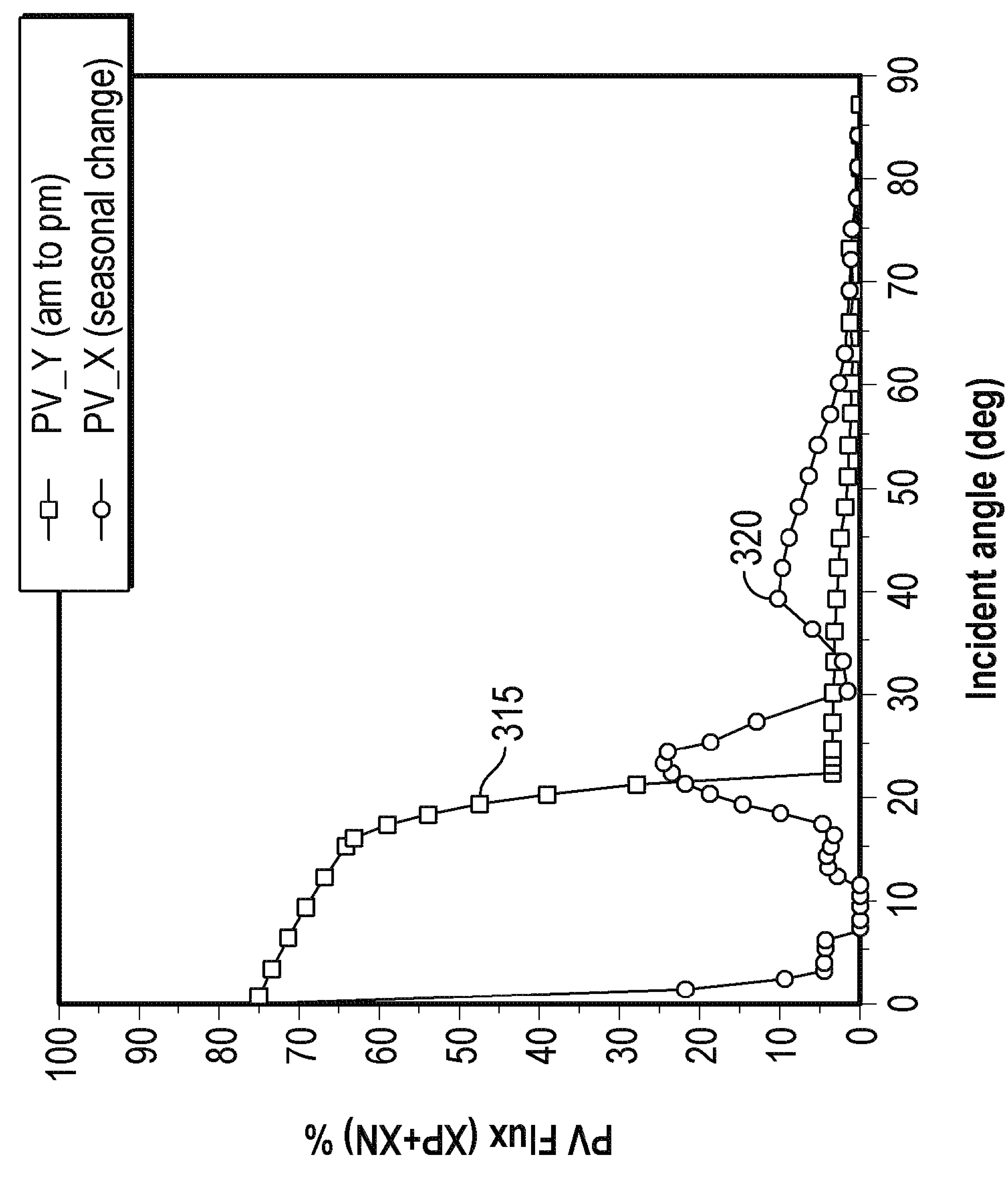

PV_Y (am to pm)
PV_X (seasonal change)
315
320
PV Flux (XP+XN) %
Incident angle (deg)
0
10
20
30
40
50
60
70
80
90
100

FIG. 5B

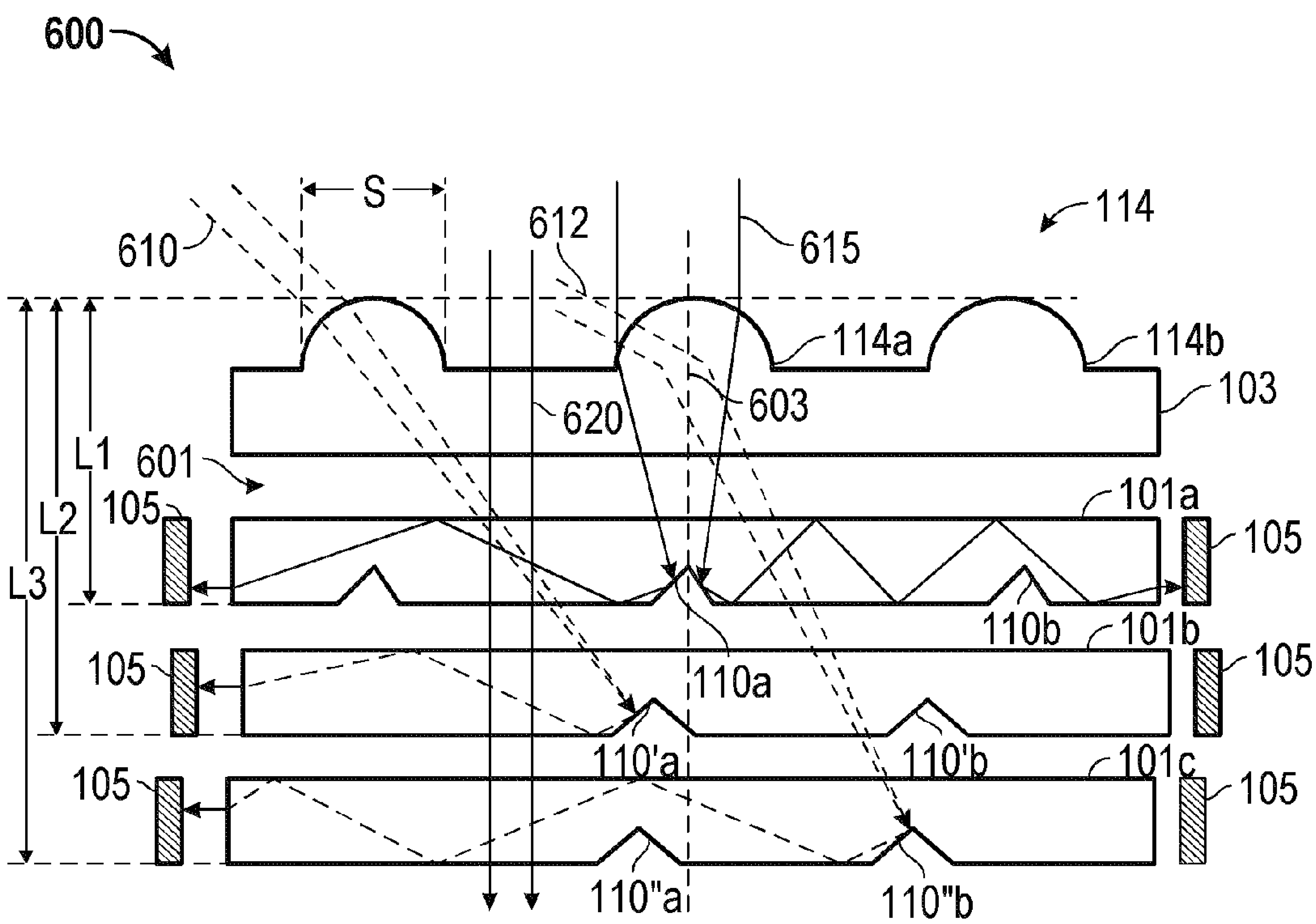

600
S
610
612
615
114
114a
114b
603
103
620
L1
601
L2
105
101a
105
L3
110b
101b
105
105
110a
110'a
110'b
101c
105
105
110"a
110"b

FIG. 6A

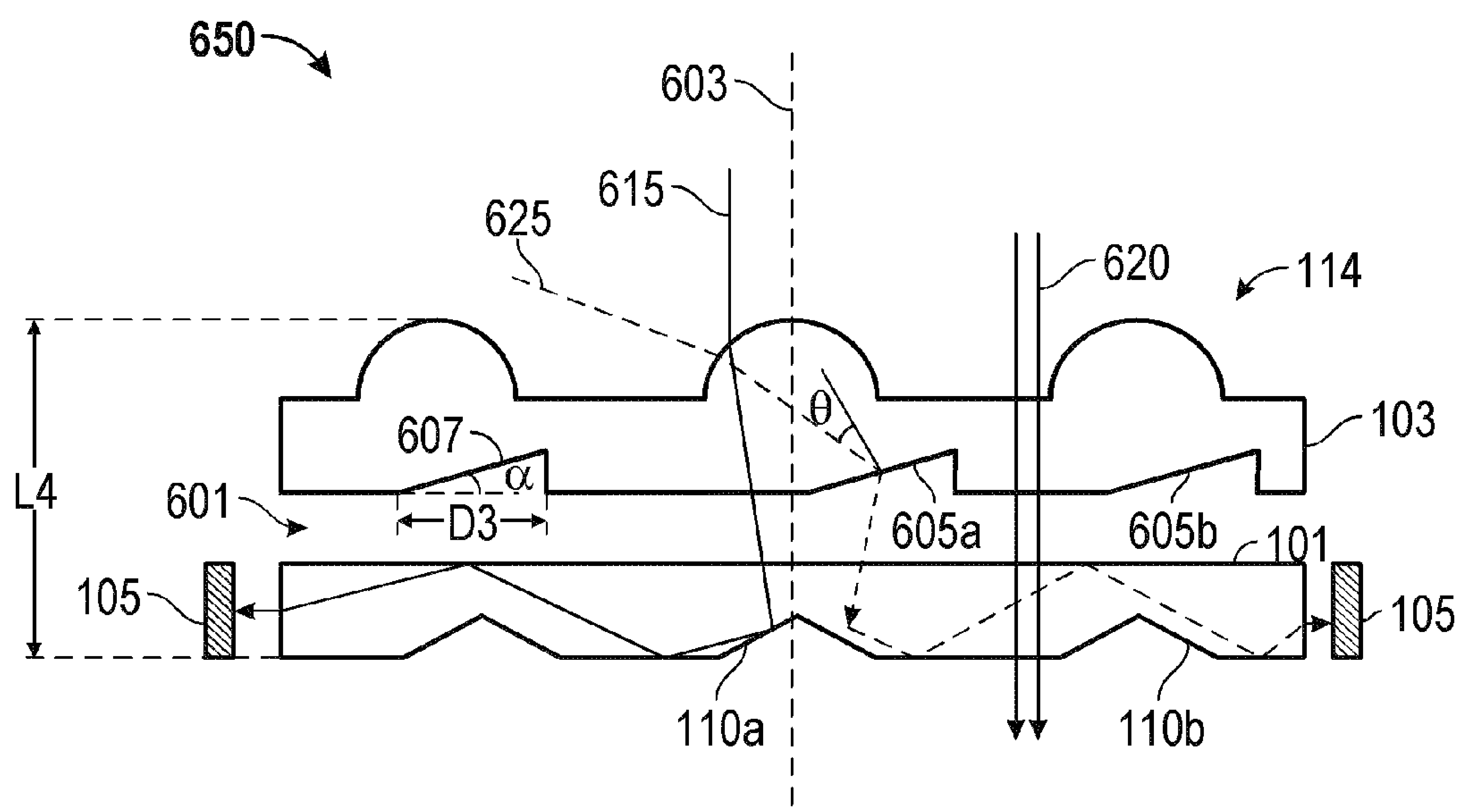

650
603
615
625
620
114
θ
103
607
α
L4
601
D3
605a
605b
101
105
105
110a
110b

FIG. 6B

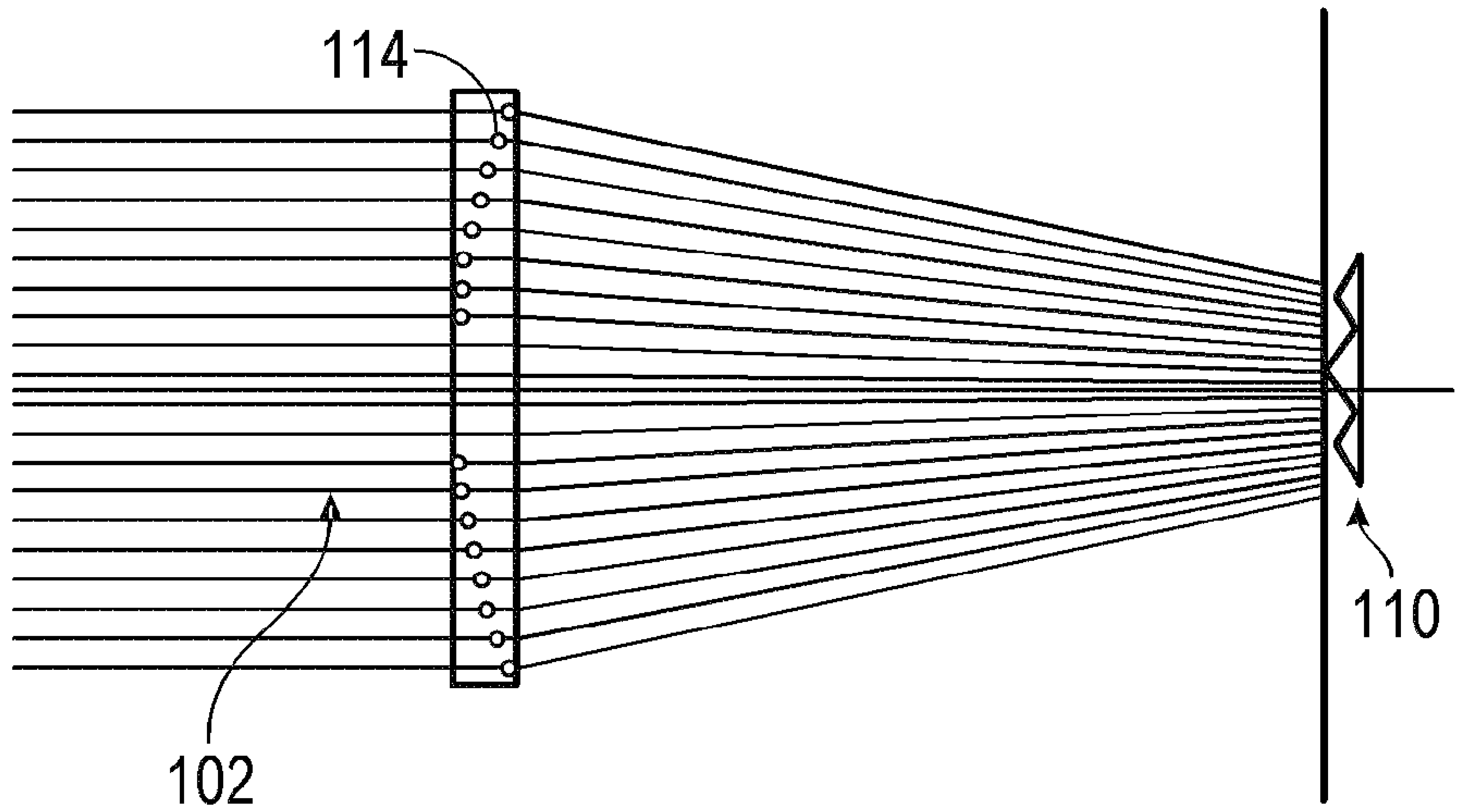


FIG. 7A

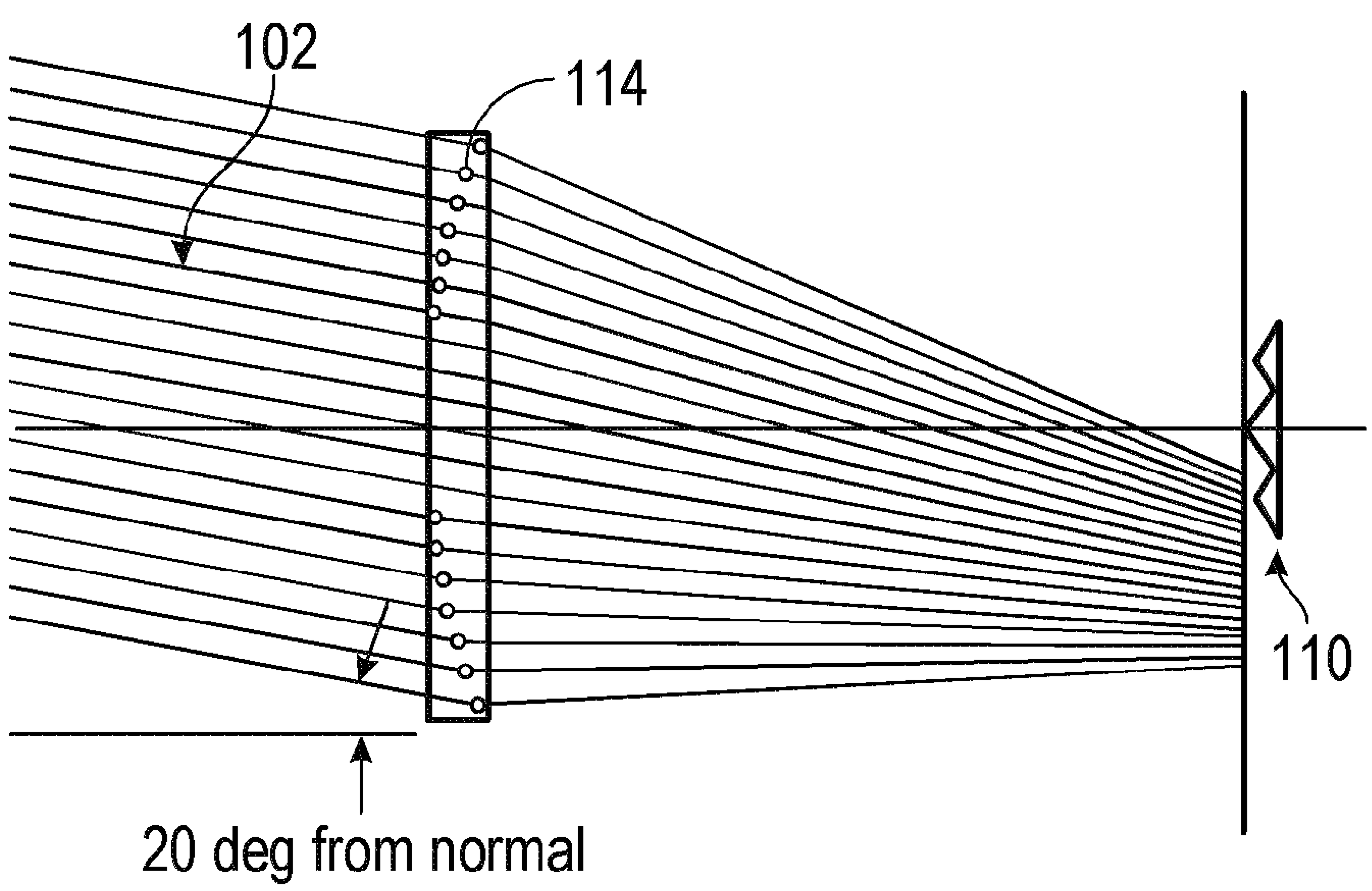


FIG. 7B

Aligned top and bottom plates

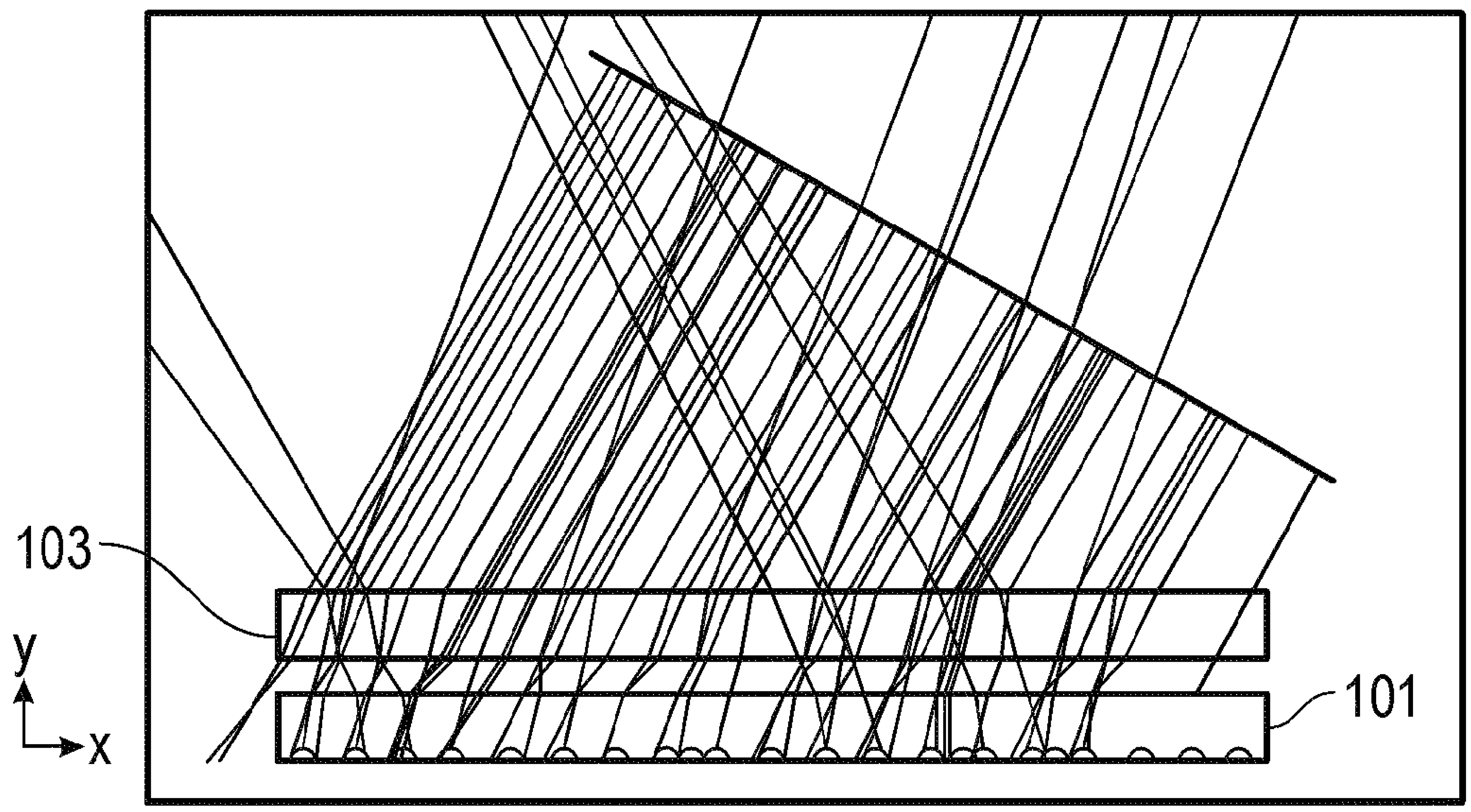


FIG. 8A1

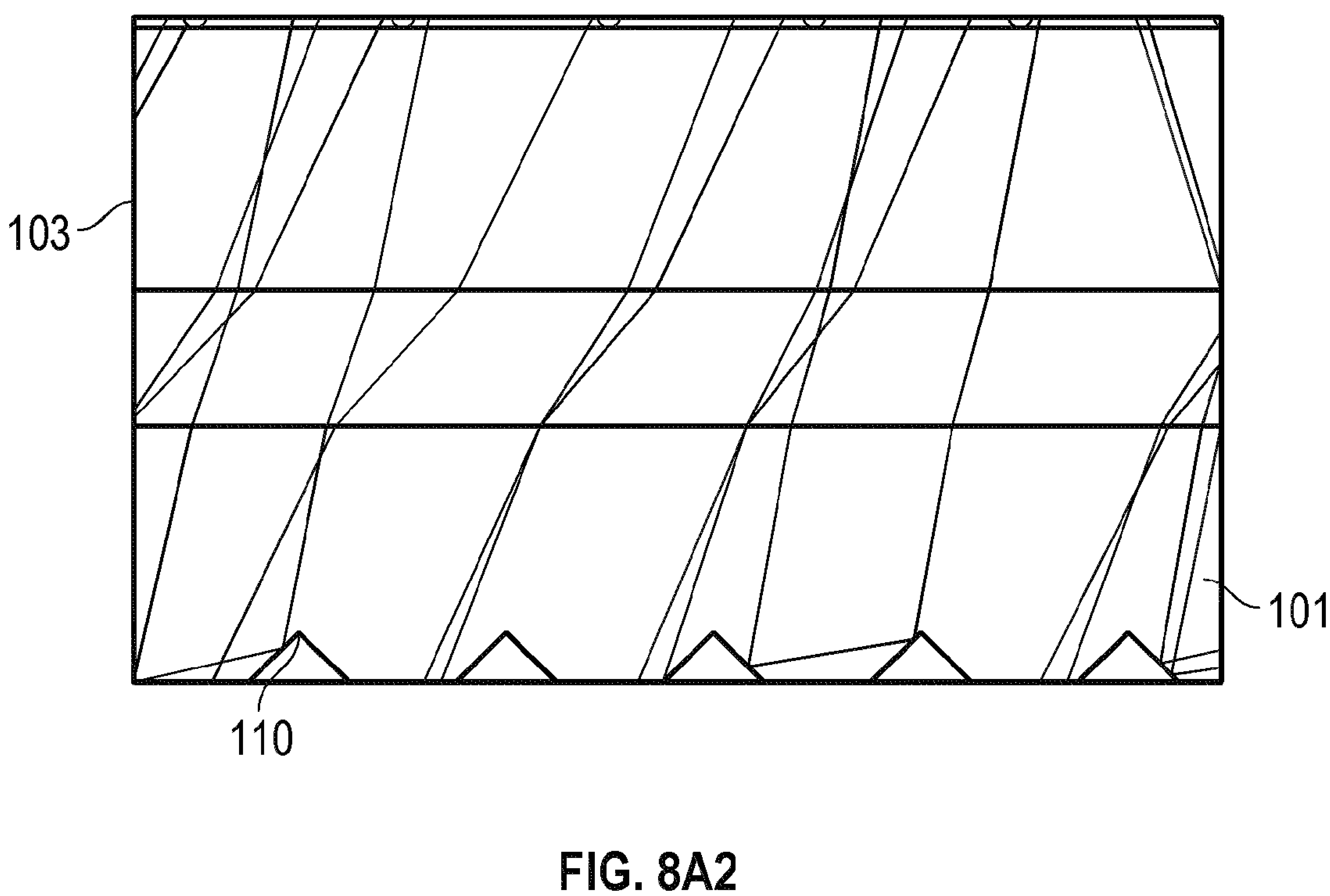


FIG. 8A2

Dislocation of 10.82688 mm

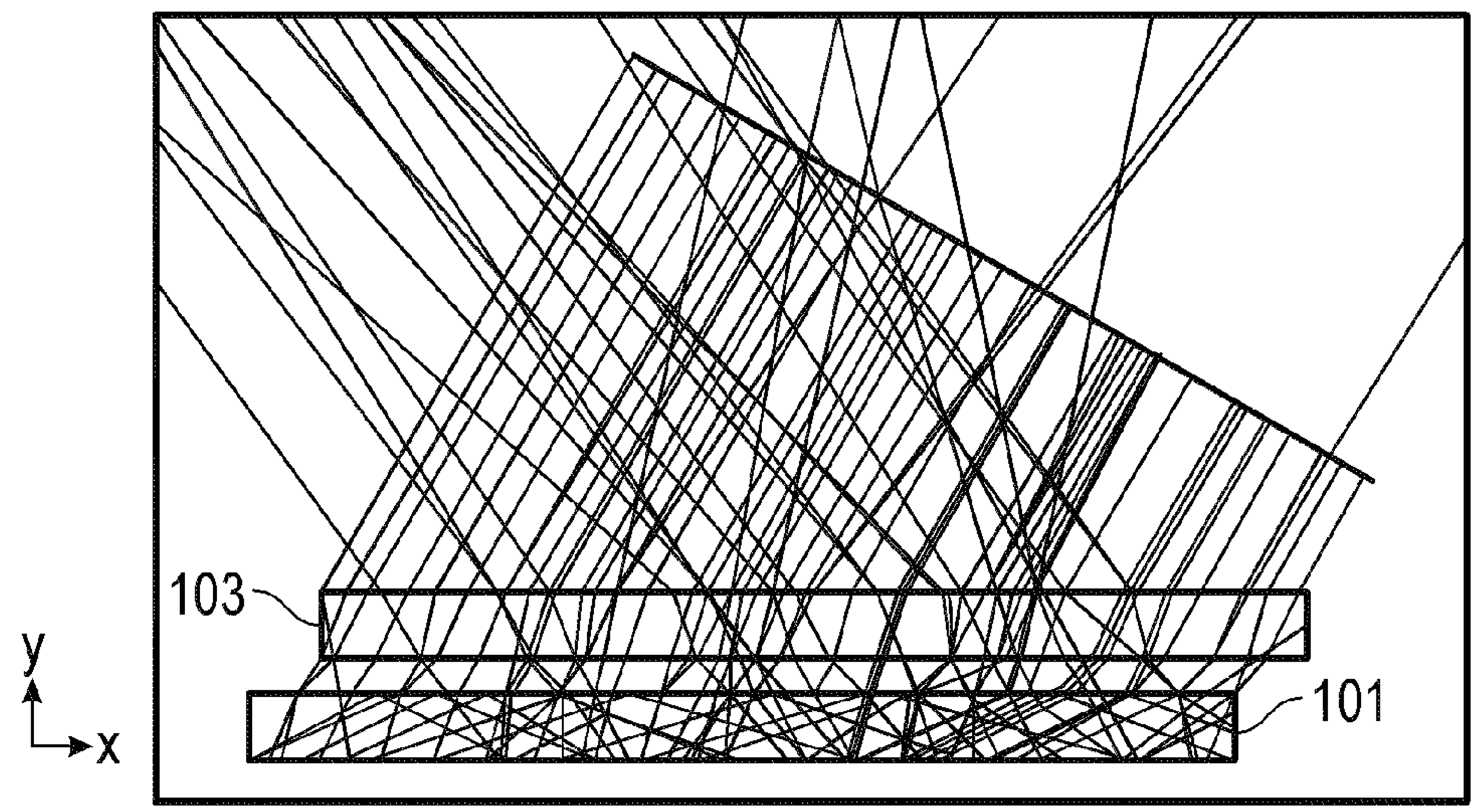


FIG. 8B1

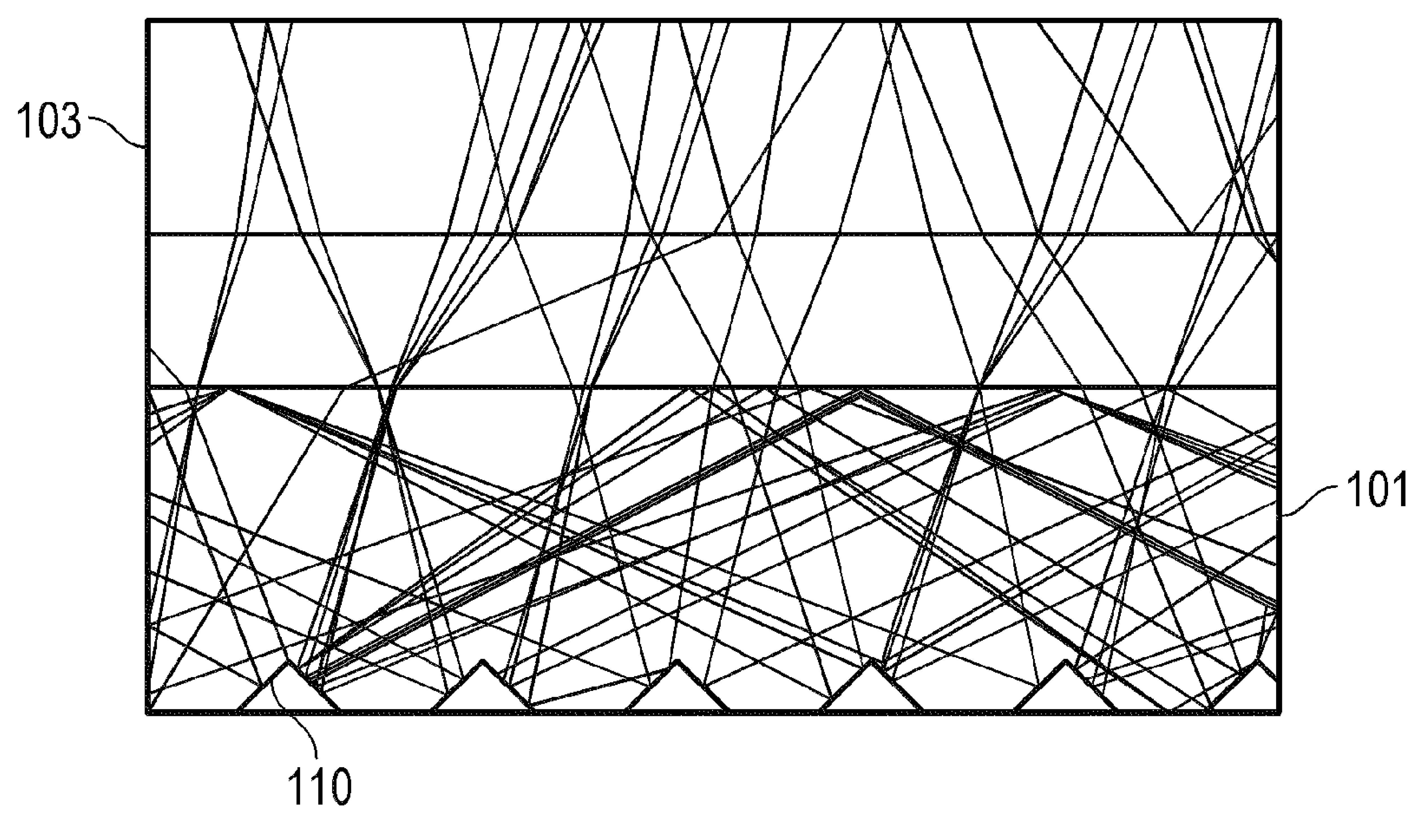


FIG. 8B2

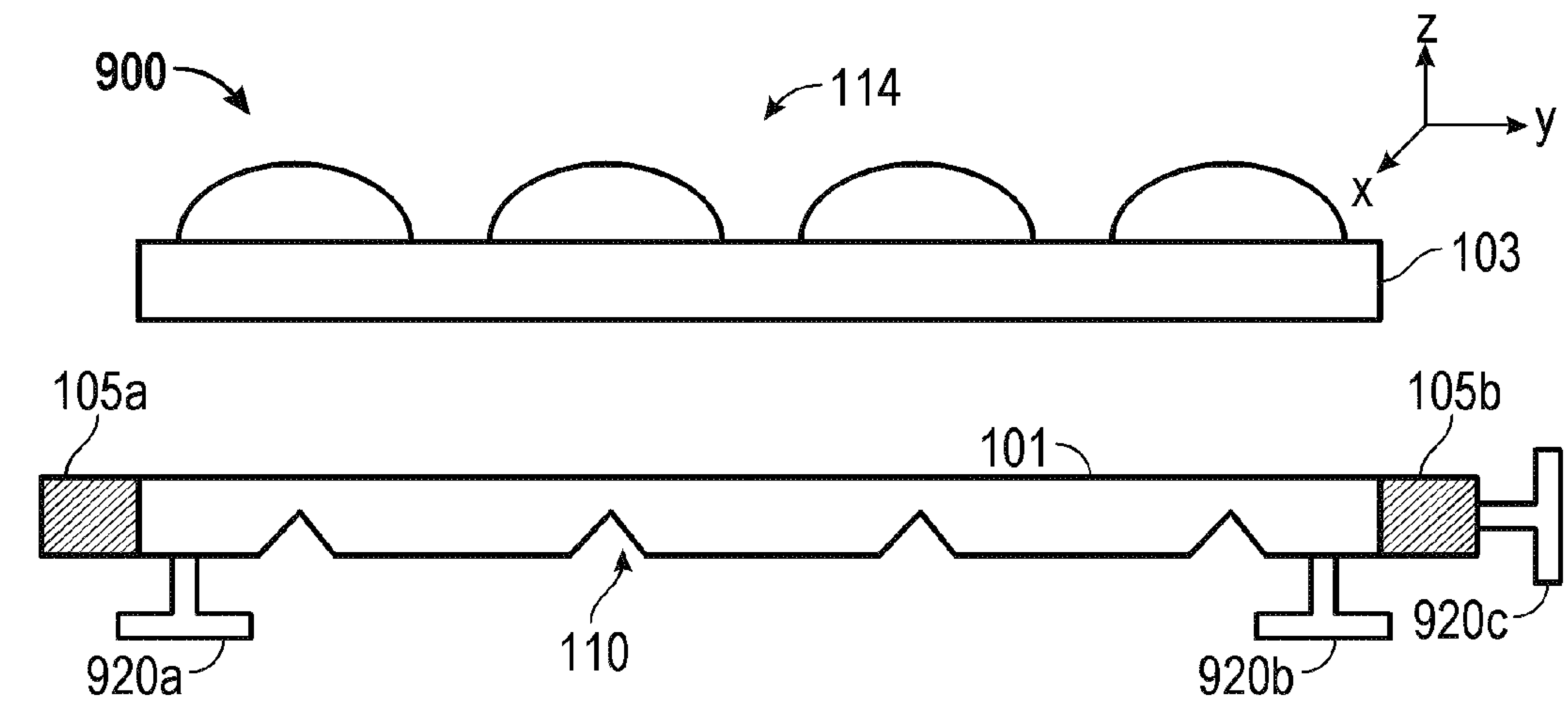


FIG. 9A

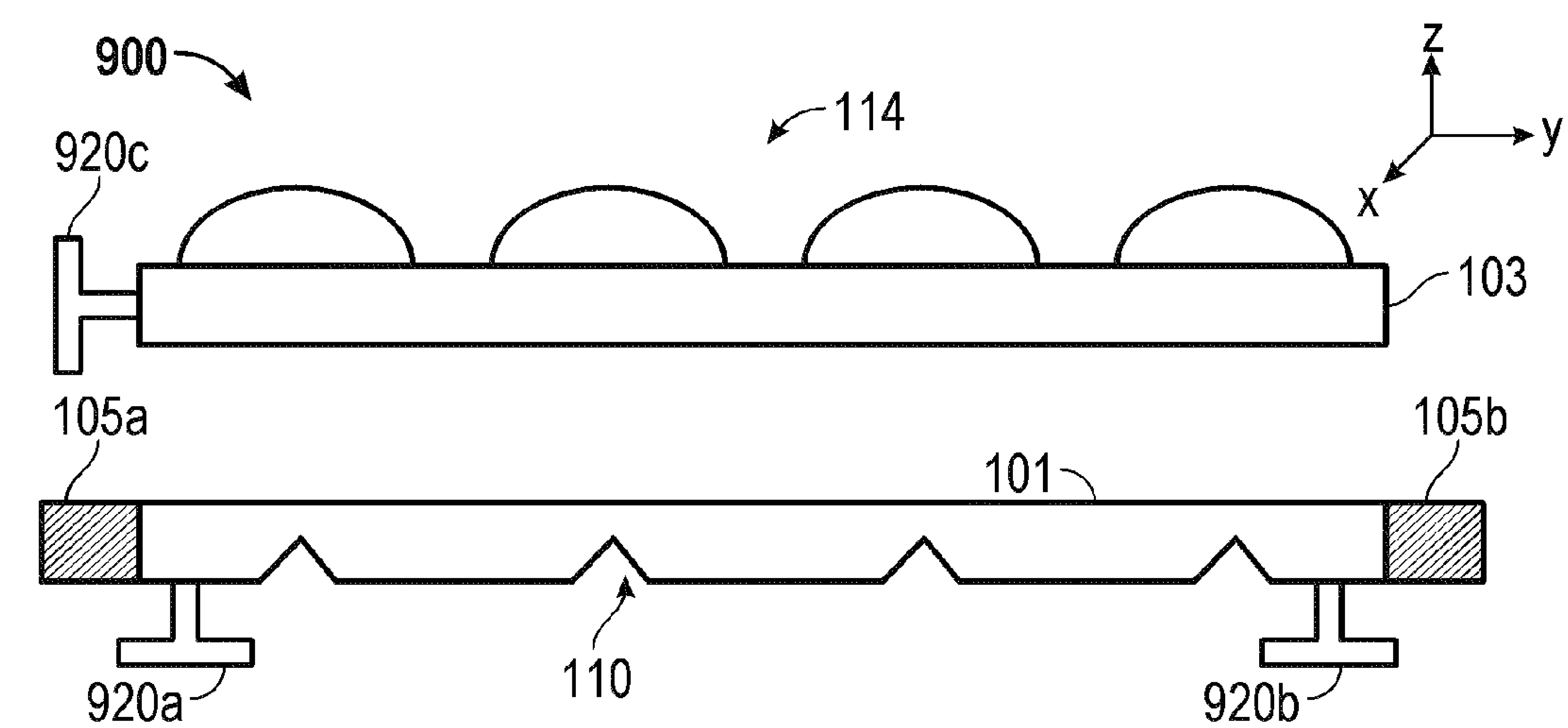


FIG. 9B

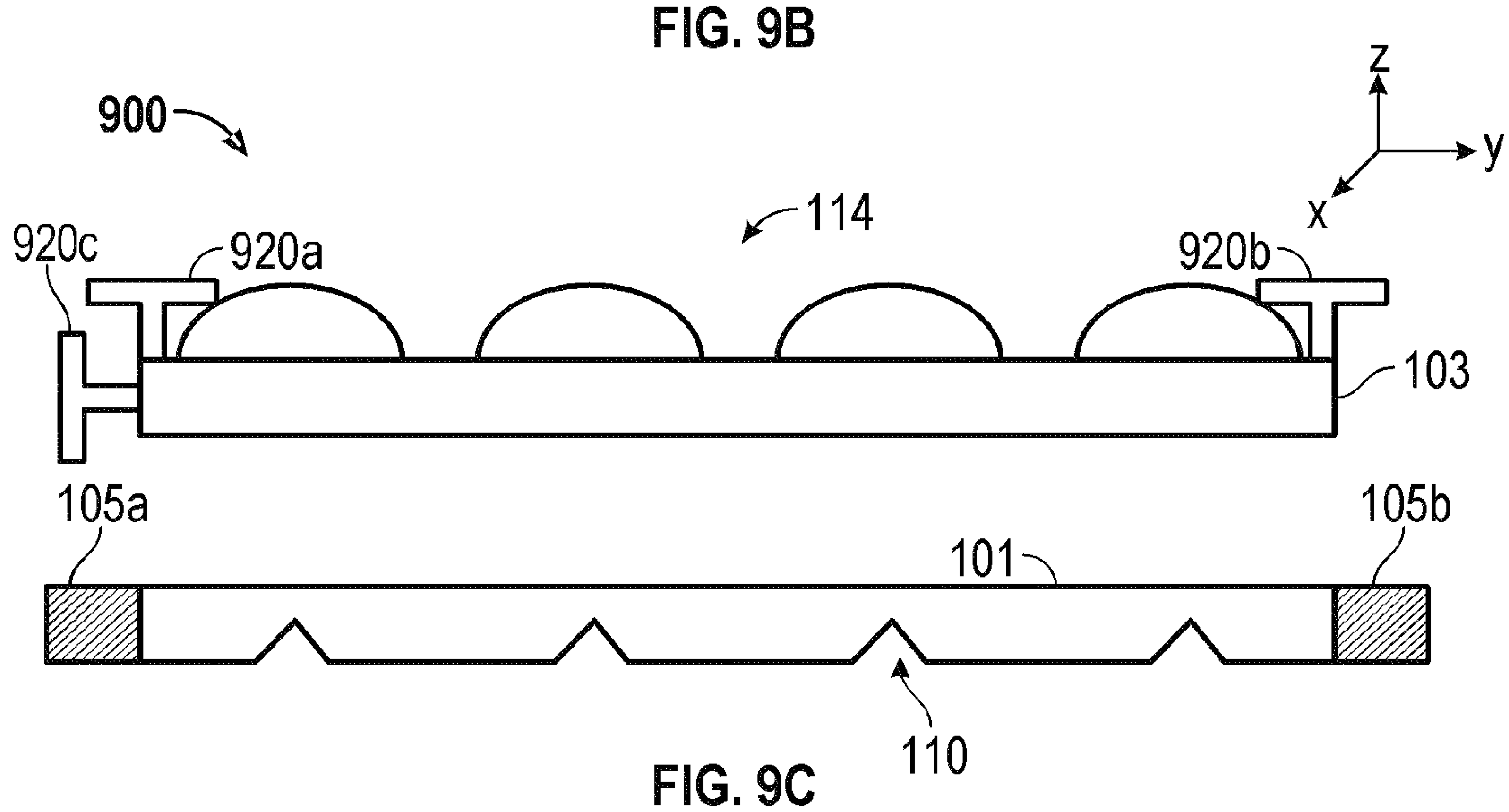


FIG. 9C

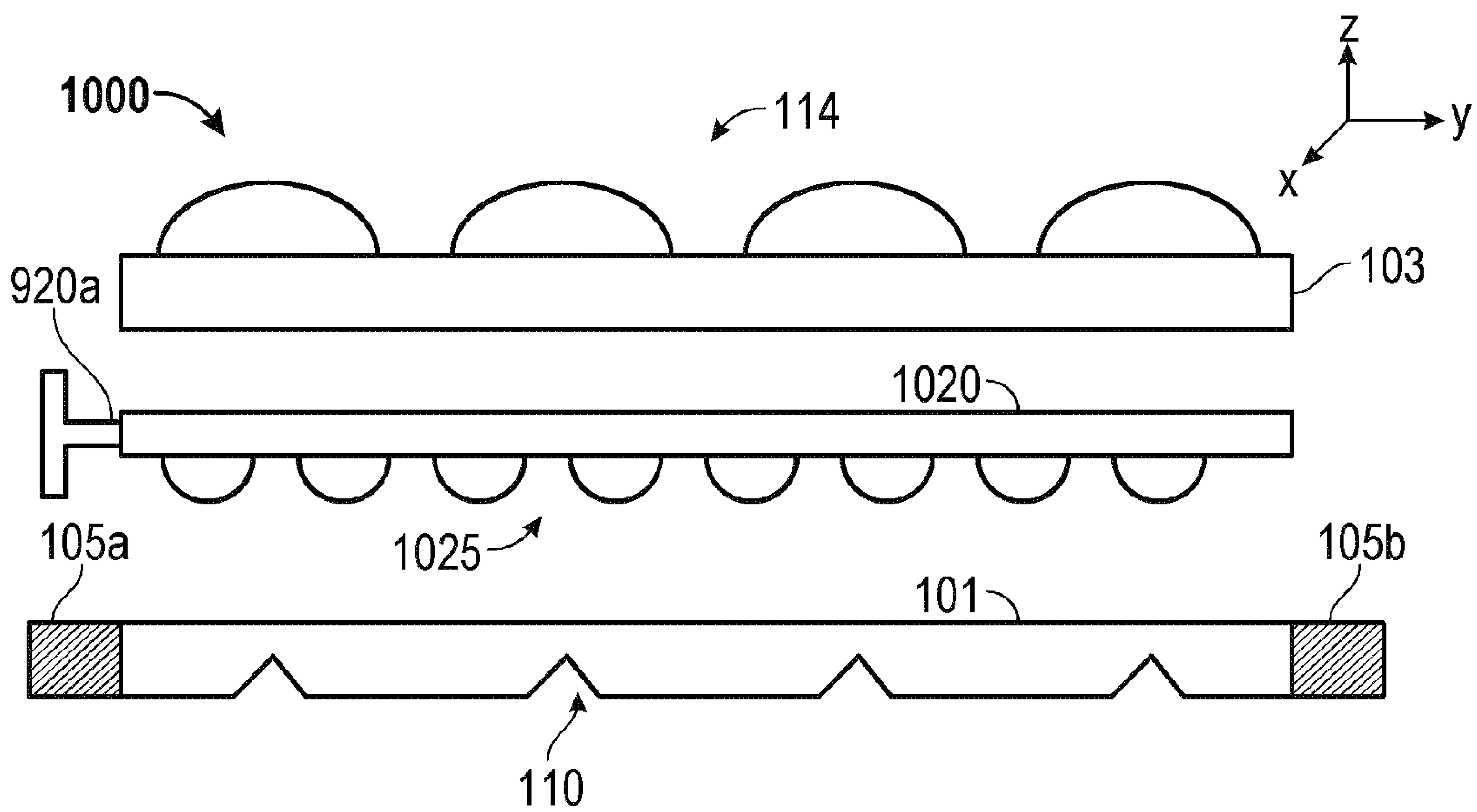


FIG. 10

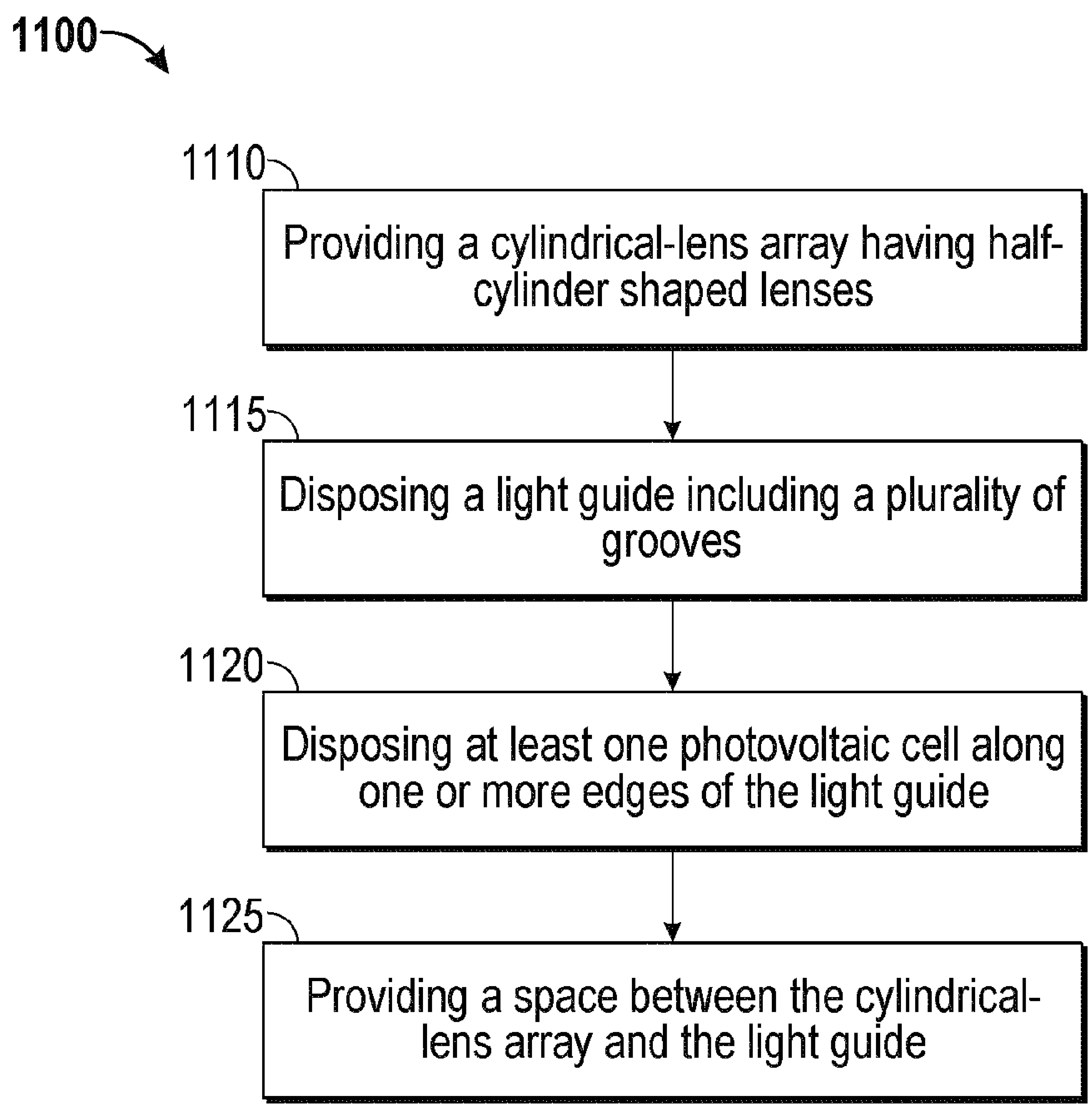


FIG. 11A

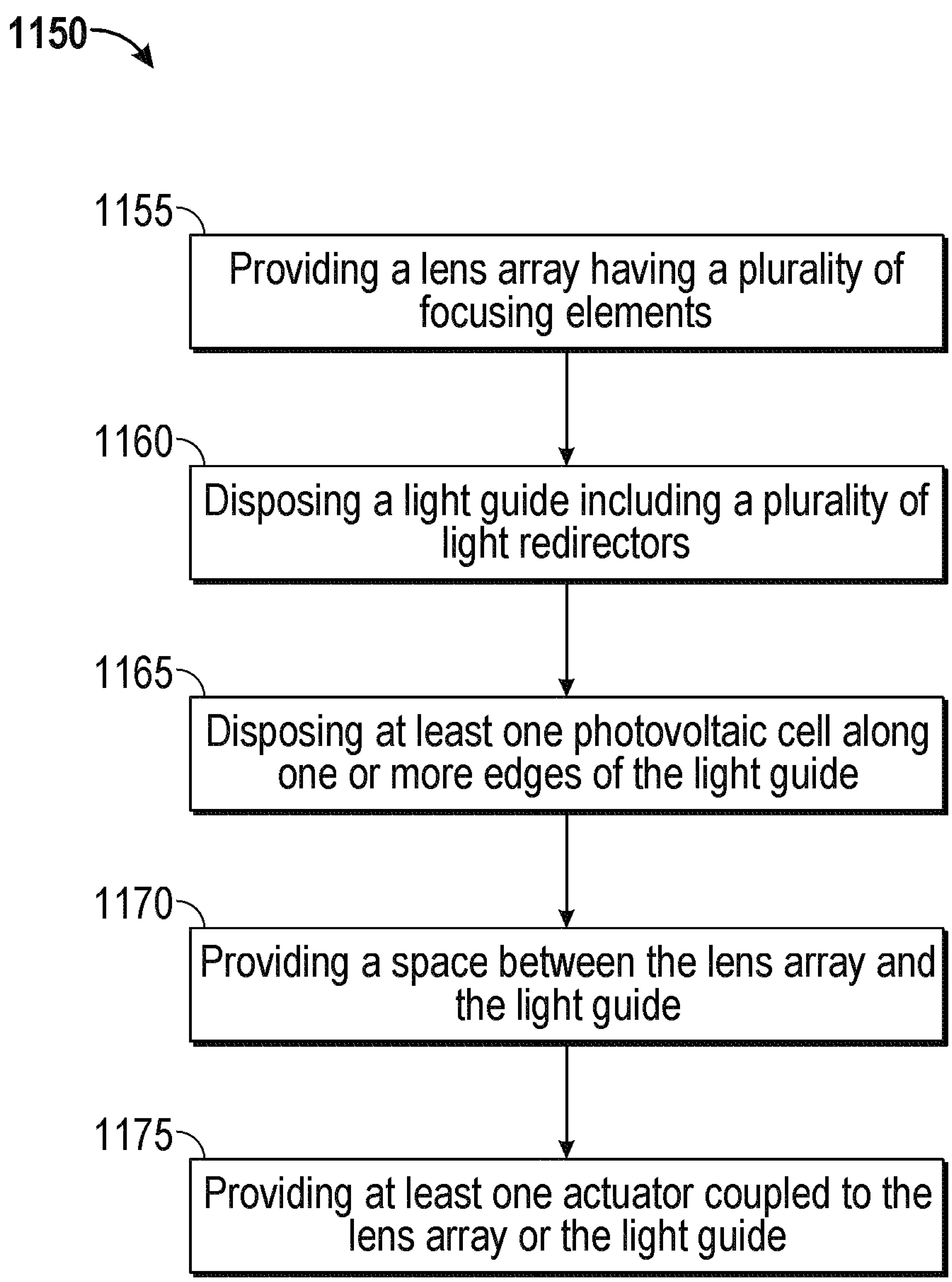

1150
1155
Providing a lens array having a plurality of focusing elements
1160
Disposing a light guide including a plurality of light redirectors
1165
Disposing at least one photovoltaic cell along one or more edges of the light guide
1170
Providing a space between the lens array and the light guide
1175
Providing at least one actuator coupled to the lens array or the light guide

FIG. 11B

WINDOW SOLAR HARVESTING MEANS

TECHNICAL FIELD

[0001] This disclosure relates to the field of light collectors and concentrators, and more particularly to using light guides including focusing optical elements that can track the diurnal and annual movement of the sun to efficiently collect solar radiation at different times during the day and the year.

DESCRIPTION OF THE RELATED TECHNOLOGY

[0002] Solar energy is a renewable source of energy that can be converted into other forms of energy such as heat and electricity. Some drawbacks in using solar energy as a reliable source of renewable energy are low efficiency in collecting solar energy and in converting light energy to heat or electricity, and the variation in the solar energy collection depending on the time of the day and the month of the year.

[0003] A photovoltaic (PV) cell can be used to convert solar energy to electrical energy. Systems using PV cells can have conversion efficiencies between 10-20%. PV cells can be made very thin and are not big and bulky as other devices that use solar energy. For example, PV cells can range in width and length from a few millimeters to 10's of centimeters. Although, the electrical output from an individual PV cell may range from a few milliwatts to a few watts, due to their compact size, multiple PV cells may be connected electrically and packaged to produce, in total, a significant amount of electricity. For example, multiple solar panels each including a plurality of PV cells can be used to produce sufficient electricity to satisfy the power needs of some homes.

[0004] Solar concentrators can be used to collect and focus solar energy to achieve higher conversion efficiency in PV cells. For example, parabolic mirrors can be used to collect and focus light on PV cells. Other types of lenses and mirrors can also be used to collect and focus light on PV cells. These devices can increase the light collection efficiency. But such systems tend to be bulky and heavy because the lenses and mirrors that are required to efficiently collect and focus sunlight can be large.

[0005] Accordingly, for many applications such as, for example, providing electricity to residential and commercial properties, charging automobile batteries and other navigation instruments, it is desirable that the light collectors and/or concentrators are compact in size.

[0006] PV materials are also increasingly replacing conventional building materials in parts of the building envelope such as windows, roofs, skylight or facades. PV materials incorporated in building envelopes can function as principal or secondary sources of electrical power and help in achieving zero-energy buildings. One of the currently available building-integrated photovoltaic (BIPV) products is a crystalline Si BIPV, which is made of an array of opaque crystalline Si cells sandwiched between two glass panels. Another available BIPV product is a thin film BIPV which is manufactured by blanket depositing PV film on a substrate and laser scribing of the deposited PV film from certain areas to leave some empty spaces and improve transmission. However, both available BIPV products described above suffer from low transmission (5-20%), disruptive appearance and serious artifacts. Additionally, the thin film BIPV may also be expensive to reasonably manufacture.

[0007] Accordingly, BIPV products that can efficiently absorb light and generate energy; improve transmission to illuminate the inside of a building; and track the diurnal/annual movement of the sun to efficiently collect light at various times of the day and different times of the year.

SUMMARY

[0008] The systems, methods and devices of the disclosure each have several innovative aspects, no single one of which is solely responsible for the desirable attributes disclosed herein.

[0009] One innovative aspect of the subject matter described in this disclosure can be implemented in a light collecting device that includes a cylindrical-lens array including a top surface for receiving incident light and a bottom surface opposite the top surface, the cylindrical-lens array having half-cylinder-shaped lenses aligned on the top surface to collect incident light, each of the half-cylinder-shaped lenses is characterized by a focal length F, the bottom surface of the cylindrical-lens array being disposed at a distance less than the focal length F such that the half-cylinder-shaped lenses directs light out of the bottom surface, and a light guide having a top surface adjacent the bottom surface of the cylindrical-lens array and a bottom surface opposite the top surface of the light guide, the light guide including a plurality of grooves oriented in the same longitudinal direction as the half-cylinder shaped lenses and disposed along the bottom surface of the light guide, each groove having a depth dimension that extends into the bottom surface of the light guide and each groove defining at least one surface angled to redirect a portion of the focused light from the half-cylinder shaped lenses to one or more edges of the light guide. The light collecting device may be configured such that about 20% to about 80% of light that enters the top surface of the cylindrical-lens array propagates through the light collecting device and out of the bottom surface of the light guide.

[0010] In some implementations of the light collecting device, the focal length F is between about 5 mm and about 20 mm. In some implementations, the distance between two consecutive grooves is between about 2 mm and 40 mm. In some implementations a transverse size of each half-cylinder shaped lens is between about 2 mm and about 10 mm. In some implementations, the light collector further includes at least one photovoltaic cell disposed along one or more edges of the light guide. In some implementations, at least two of the half-cylinder-shaped lenses are laterally spaced apart by a first spacing distance. In some implementations, at least two of the half-cylinder-shaped lenses are laterally spaced apart by a second spacing distance, the second spacing distance being different from the first spacing distance. In some implementations, the first spacing distance is between about 0.1 mm and 25 mm and the second spacing distance is between about 0.1 mm and 100 mm. The first spacing distance may be the same for at least two pairs of adjacent half-cylinder shaped lenses in the cylindrical-lens array. In some implementations, the first spacing distance is between about 0.1 mm and 100 mm. In some implementations, the at least two half-cylinder-shaped lenses are characterized by a transversal size, wherein the first spacing distance is less than the transversal size. In some implementations, each of the plurality of grooves is vertically aligned with a center portion of one of the half-cylinder shaped lens. In some implementations, a set of at least two or more grooves are vertically aligned with a center portion of one of the half-cylinder shaped lenses such that light focused by the one half-cylinder shaped lens is incident on the at least two or more grooves and redirected by the at least two or more grooves towards the at least one photovoltaic cell.

[0011] In some implementations of the light collection device, the apex of the grooves are vertically offset by approximately 0.1 mm to 5 mm from the focus of the plurality of half-cylinder shaped lenses. In some implementations, the plurality of grooves are spaced apart by a first gap of between about 0.1 mm and 200 mm. In some implementations, a set of the plurality of grooves are offset with respect to an optical axis of corresponding half-cylinder shaped lenses. At least two adjacent grooves may be spaced apart by a first gap and at least two adjacent grooves are spaced apart by a second gap different from the first gap. Each of the plurality of grooves may include two or more turning features. In some implementations, the turning features include at least one of: prismatic features, holographic features, diffractive features, refractive features, reflective features and scattering features. In some implementations, each of the plurality of grooves includes two or more grooves. The light guide may have a refractive index characteristic greater than a refractive index of the cylindrical lens-array. In some implementations, the light collector device further includes a substance having a refractive index lower than a refractive index of the light guide, the substance sandwiched between cylindrical-lens array and the light guide. In some implementations, the light collector device further includes a gap between the light guide and the cylindrical-lens array. In some implementations, an amount of light transmitted through the light collecting device can be selected by selecting a height of the gap. In some implementations the light collector device may be configured as a window of a building.

[0012] Another innovative implementations includes a light collecting device, including a plurality of means for focusing incident light configured in an array plate, each of focusing means characterized by a focal length F such that the focusing means half-directs light out of a bottom surface of the array plate, and means for guiding light disposed adjacent to the bottom surface of the array plate, the light guiding means including means for redirecting light oriented in the same longitudinal direction as the focusing means and disposed along a bottom surface of the guiding means. The light collecting device may be configured such that about 20% to about 80% of light that enters plurality of focusing means propagates through the light collecting device and out of the bottom surface of the light guiding means.

[0013] In some implementations, the light collecting device further includes at least one photovoltaic cell disposed along one or more edges of the light guiding means. In some implementations, the plurality of focusing means includes a plurality of half-cylinder-shaped lenses. In some implementations, the light guiding means includes a light guide having a top surface adjacent the bottom surface of the cylindrical-lens array and a bottom surface opposite the top surface of the light guide, and wherein the light redirecting means includes a plurality of grooves oriented in the same longitudinal direction as the half-cylinder shaped lenses and disposed along the bottom surface of the light guide, each groove having a depth dimension that extends into the bottom surface of the light guide and each groove defining at least one surface angled to redirect a portion of the focused light from the half-cylinder shaped lenses to one or more edges of the light guide.

[0014] Another innovative implementation includes a method of manufacturing a light collecting device, the method including providing a cylindrical-lens array including a top surface for receiving incident light and a bottom surface opposite the top surface, the cylindrical-lens array having half-cylinder-shaped lenses aligned on the top surface to collect incident light, each of the half-cylinder-shaped lenses is characterized by a focal length F, the bottom surface of the cylindrical-lens array being disposed at a distance less than the focal length F such that the half-cylinder-shaped lenses directs light out of the bottom surface, and disposing a light guide having a top surface adjacent the bottom surface of the cylindrical-lens array and a bottom surface opposite the top surface of the light guide, the light guide including a plurality of grooves oriented in the same longitudinal direction as the half-cylinder shaped lenses and disposed along the bottom surface of the light guide, each groove having a depth dimension that extends into the bottom surface of the light guide and each groove defining at least one surface angled to redirect a portion of the focused light from the half-cylinder shaped lenses to one or more edges of the light guide. The plurality of half-cylinder shaped lenses may be disposed laterally spaced apart to define one or more lens spacings LS, the plurality of grooves are disposed laterally spaced apart to define one or more groove spacings GS, and the plurality of grooves are disposed at a distance D from the half-cylinder shaped lenses relative to a focal length of the half-cylinder shaped lenses, and the lens spacings LS, the groove spacings GS and the distance D are selected such that about 20% to about 80% of light that enters the light collecting device is transmitted through the light collecting device and propagates out of the bottom surface of the light guide. In some implementations, the method further includes providing a space between the cylindrical-lens array and the light guide. In some implementations, the method further includes providing a material having a lower refractive index than the refractive index of the light guide in the space. In some implementations, the method further includes disposing at least one photovoltaic cell along one or more edges of the light guide.

[0015] Details of one or more implementations of the subject matter described in this specification are set forth in the accompanying drawings and the description below. Other features, aspects, and advantages will become apparent from the description, the drawings, and the claims. Note that the relative dimensions of the following figures may not be drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Example implementations disclosed herein are illustrated in the accompanying schematic drawings, which are for illustrative purposes only.

[0017] FIG. **1** illustrates an implementation of a light collector including a light guide that is optically coupled to a PV cell.

[0018] FIG. **2**A is a schematic that illustrates a perspective view of an implementation of a light collector that is configured to efficiently collect light throughout the day.

[0019] FIG. **2**B illustrates a cross-sectional view of an implementation of a linear v-groove including planar facets S**1** and S**2** arranged at an angle θ with respect to each other.

[0020] FIGS. **2**C-**2**E illustrate cross-sectional views of the implementation illustrated in FIG. **2**A and depict the light collection at various times during the day.

[0021] FIGS. **3**A-**3**C illustrate perspective views of a portion of the implementation illustrated in FIG. **2**A and depict the light collection at various times during the day.

[0022] FIGS. **4**A and **4**B illustrate two different implementations of the light collector illustrated in FIG. **2**A, each implementation having a different density (or fill factor) of the half-cylinder shaped lenses and the corresponding plurality of redirecting features.

[0023] FIG. **5**A depicts an implementation of the light collector located at the equator on the earth's surface.

[0024] FIG. **5**B illustrates the simulated optical efficiency (i.e., light diverting efficiency) as a function of the incidence angle for implementation illustrated in FIG. **5**A.

[0025] FIGS. **6**A and **6**B illustrate different implementations of a light collector including lenses and a plurality of light redirecting features, each implementation configured to collect light that is incident along a first direction that is normal to the light collector and a second direction that is oblique to the light collector.

[0026] FIGS. **7**A and **7**B illustrate the effect of a change in the incidence angle of sunlight due to the earth's rotation on the light diverting efficiency of an implementation of the light collector illustrated in FIG. **1**.

[0027] FIGS. **8**A**1**-**8**B**2** are simulation results showing the effect of the relative horizontal or vertical movement of different portions of an implementation of the light collector illustrated in FIG. **1**.

[0028] FIGS. **9**A-**9**C illustrate different implementations of a light collector **800** including a focusing plate **103** and a light guide **101** that can be moved horizontally or vertically with respect to each other to maintain uniform light diverting efficiency through-out the day and/or to transmit a certain amount of incident light through the light collector.

[0029] FIG. **10** illustrates an implementation of a light collector that can actively track the movement of the sun across the sky.

[0030] FIGS. **11**A and **11**B are flow charts illustrating two different examples of a method of manufacturing an implementation of a light collecting device.

[0031] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0032] The following detailed description is directed to certain implementations for the purposes of describing the innovative aspects. However, the teachings herein can be applied in a multitude of different ways. As will be apparent from the following description, the innovative aspects may be implemented in any device that is configured to receive radiation from a source and generate power using the radiation. More particularly, it is contemplated that the innovative aspects may be implemented in or associated with a variety of applications such as providing power to residential and commercial structures and properties, providing power to electronic devices such as laptops, personal digital assistants (PDA's), wrist watches, calculators, cell phones, camcorders, still and video cameras, MP3 players, etc. Some of the implementations described herein can be used in BIPV products such as windows, roofs, skylights, doors or facades. Some of the implementations described herein can be used to charge vehicle or watercraft batteries, power navigational instruments, to pump water and for solar thermal generation. The implementations described herein can also find use in aerospace and satellite applications, and other solar power generation applications.

[0033] As discussed more fully below, in various implementations described herein, a solar collector and/or concentrator is optically coupled to a PV cell such that light incident on a portion of the collector is provided to the PV cell to generate electrical power. For clarity of description, "solar collector," "light collector," or simply "collector" can be used to refer to either or both a solar collector and a solar concentrator, unless otherwise indicated. The light collector can include a plurality of focusing elements that can receive light incident on an exposed surface of the light collector and direct the received light towards a light guide as a focused beam of light. The light guide can include a plurality of redirecting elements that can redirect the focused beam of light towards one or more PV cells that are disposed along one or more edges of the light guide. In various implementations described herein the size, density, and fill factor of the plurality of focusing elements can be selected such that a portion of the light incident on the light collector is transmitted out of the light collector.

[0034] In various implementations described herein, the focusing elements can include a plurality of half-cylinder shaped lens, each half-cylinder shaped lens having a curved surface that is disposed about a cylindrical axis. The surface of each half-cylinder shaped lens can have a circular, an elliptical or a parabolic cross-section. Each of the plurality of half-cylinder shaped lenses can be designed and oriented such that light from the sun is incident on at least a portion of the lens curved surface such that the light is focused along a single line by each lens at any one time as the sun's position relative to earth moves changes from east to west during the day. In such implementations, the light redirecting elements can include elongate grooves that are oriented in the same direction as the cylindrical axis and positioned at a distance equal to the focal length of the plurality of half-cylinder shaped lenses. In such implementations, light from the sun can be focused by each of the half-cylinder shaped lens is incident on a corresponding elongate groove throughout the day.

[0035] In various implementations, the light collector can include one or more actuators that can change the relative horizontal and/or vertical positions between the plurality of focusing elements and the plurality of light redirecting elements. Changing these relative positions can change the position of the plurality of light redirecting elements relative to the focal point which can change the focal point to increase the amount of photovoltaic power generated and/or change the amount of light transmitted through the light collector. Additionally, the one or more actuators can be useful to adjust the relative positions of the focusing elements and the light redirecting features corresponding to the movement of the sun through the day or the year, thereby increasing the efficiency of light collection.

[0036] Particular implementations of the subject matter described in this disclosure can be implemented to realize one or more of the following potential advantages. A light collector, such as, for example, the implementations described herein can be used to collect, concentrate, and direct sunlight or ambient light to PV cells in devices that convert light energy into electricity with increased efficiency and lower cost. Additionally, the implementations described herein can be configured to transmit a portion of the incident sunlight or ambient light through the light collector. Accordingly, the various implementations of the light collector described herein can be used to generate PV power while simultaneously providing illumination from received incident light. Thus, the implementations described herein can be integrated in architectural structures such as, for example, windows, roof, skylights, or facades to simultaneously generate photovoltaic power and transmit sunlight or ambient light to the interior of the architectural structures. Some implementations of the light collector, described herein can efficiently collect light at various times during the day or the year. For example, the implementations of the light collector described herein can efficiently collect light incident at noon when sun is overhead and sunlight is incident at angles closer to a surface normal of the light collector as well as in the mornings and evening when light is incident at non-normal angles.

[0037] FIG. **1** illustrates an implementation of a light collector **100** including a light guide **101** that is optically coupled to a PV cell **105**. The light guide **101** includes a forward surface **112** and a rearward surface **113**, opposite the forward surface **112**. A person having ordinary skill in the art will appreciate that the terms "forward" and "rearward" as used in referring to light collector surfaces herein do not indicate a particular absolute orientation, but instead are used to indicate a light collecting surface ("forward surface") on which natural light is incident and a surface where a portion of the incident light received on the forward surface can propagate out from ("rearward surface"). In this implementation, light incident on the forward surface **112** has first passed through a focusing plate **103**. A plurality of edges **116** are enclosed between the forward and rearward surfaces **112** and **113** of the light guide **101**. As illustrated in FIG. **1**, a PV cell **105** is disposed with respect to one of the edges **116** of the light guide **101**. Although only one PV cell **105** is illustrated in FIG. **1**, it is understood that one or more additional PV cells can be disposed along one or more of the other edges **116** of the light guide **101**. In various implementations, the light guide **101** may be optically coupled to the PV cell **105** by using optical coupling elements such as lenses, fibers, prisms, etc. The focusing plate **103** includes an array of focusing elements **114** is disposed on, or over, the forward surface **112** of the light guide **101**. The array of focusing elements **114** are configured to focus the received ambient light **102** onto the light guide **101** as a focused beam of light represented by ray **115**. The light guide **101** illustrated in FIG. **1** includes a plurality of light redirecting features **110** that are configured to divert or turn a first portion of light that is incident on the forward surface of the light guide **101** towards the PV cell **105**. The array of focusing elements **114** and the plurality of light redirecting features **110** can be configured such that a second portion of light that is incident on the forward surface is transmitted out of the light guide **101** through the rearward surface **113**. In FIG. **1**, ray **120** is representative of a second portion of the received light that propagates out of the light guide **101** from the rearward surface **113**. In FIG. **1**, ray **125** is a representative of a diverted portion of light which propagates through the light guide **101** by successive total internal reflections of the forward and the rearward surfaces towards the PV cell **105**. In various implementations, the light guide **101** can include a transparent or transmissive material such as glass, plastic, polycarbonate, polyester or cyclo-olefin. The forward and rearward surfaces **112** and **113** of the light guide **101** can be parallel or nearly so. In other implementations, the light guide **101** can be wedge shaped such that the forward and rearward surfaces are inclined with respect to each other. The light guide **101** may be formed as a plate, sheet or film, and fabricated from a rigid or a semi-rigid material. In various implementations, portions of the light guide **101** may be formed from a flexible material.

[0038] In various implementations, the plurality of light redirecting features **110** may be disposed on the forward or rearward surfaces **112** and **113** of the light guide **101**. The plurality of light redirecting features **110** can include elongated grooves, v-grooves, scattering features, optical refractive, reflective or diffractive features. In some implementations, the light guide **101** can include a substrate and a film or a plate provided with the plurality of light redirecting features **110** can be adhered or attached to the substrate. In various implementations, the plurality of light redirecting features **110** can be manufactured using methods such as etching, embossing, imprinting, lithography, etc. In some implementations, the plurality of light redirecting features **110** can include white paint that is applied to the forward or rearward surfaces **112** and **113** of the light guide **101**.

[0039] In various implementations, the array of focusing elements **114** can include a plurality of lenses, a lenslet array, and an array of microlenses. The array of focusing elements **114** can have hemispherical, hemi-cylindrical, parabolic or elliptical surfaces. Each of the plurality of focusing elements in the array **114** can be characterized by a focal length F. The light guide **101** can be disposed relative to the focusing plates **103** such that incident light is focused onto the plurality of light redirecting features **110** by the array of focusing elements **114**. In some implementations, the array of focusing elements **114** can be disposed on a rearward surface of the focusing plate **103**. The focusing plate **103** can be rigid or flexible. In various implementations, the focusing plates **103** can be separated from the forward surface of the light guide **101** by a gap. In some implementations, the gap can include a layer of material having a lower refractive index than the refractive index of the material of the light guide. For example, the gap can include air or nitrogen. In other implementations, the gap can include a material that matches the refractive index of the array of focusing elements **114** to the refractive index of the light guide **101**. In some implementations, the array of focusing elements **114** can be disposed on the forward surface of the light guide **101** and the plurality of light redirecting features **110** can be disposed on the rearward surface of the light guide **101**.

[0040] An implementation similar to the light collector **100** illustrated in FIG. **1** can be used as a (building-integrated photovoltaic) BIPV product (for example, window, skylight, facade, door, glazing, or a curtain wall). A BIPV product using a light collector **100** or other implementations of a light collector as described herein can reduce the cost of the BIPV product since the PV cells are used only at the edges of the light guide (for example, light guide **101**). High efficiency Si or III-V solar cells can be used in various implementations to increase the photoelectric conversion efficiency. A BIPV product using a light collector **100** or other implementations of a light collector as described herein can additionally reduce color dispersion and image distortion; serve as thermal barrier and block solar radiation thereby aid in reducing heating and cooling costs; be designed to meet advanced building codes and standards; minimize fire hazard; supply better daylight as compared to conventional BIPV products; recycle indoor lighting energy; help in achieving "net zero building" by generating electric power, be cut into arbitrary shapes and sizes according to the building requirement; be compatible with curved glass windows and be aesthetically pleasing as conventional windows. Additionally, a BIPV product using a light collector **100** or other implementations of a light collector as described herein can be used for windows, privacy screens, skylights, etc. since the amount of light transmitted through the collector can be varied or controlled by varying or controlling a density or fill factor of the plurality of optical features during manufacturing. A BIPV product using a light collector **100** or other implementations of a light collector as described herein can be used to compensate for diurnal movement of the sun with or without mechanically displacing portions of the light collector to increase the efficiency of light collection.

[0041] FIG. **2**A illustrates a perspective view of an implementation of a light collector **200** that is configured to efficiently collect light at all times of the day. The light collector **200** can divert a first portion of the collected light towards one or more PV cells **210** and transmit a second portion of the collected light out of the light collector **200**. The illustrated light collector **200** can simultaneously generate PV power and provide illumination to the interior of the structure it is disposed on. Accordingly, the illustrated light collector **200** can be used as a power generating window or skylight. The light collector **200** is a two-piece light collecting structure that includes a focusing plate **201** having a cylindrical lens array including a plurality of half-cylinder shaped lenses (or focusing lenses) **204***a*, **204***b* and **204***c* and a light guide **205** that includes a plurality of light redirecting features **207** (e.g., **207***a*, **207***b* and **207***c*, also referred to as "redirecting features **207**" for ease of reference). The light collector **200** can also include other structures which provide structural support or change an optical characteristic. Where appropriate, structures and features of light guide **101** discussed above may be incorporated into light guide **205**. For example, light guide **205** may be made of the same or similar materials as those discussed for light guide **101**. As another example, the plurality of redirecting features **207** can be fabricated using methods similar to the fabrication of the plurality of light redirecting features **110**.

[0042] The PV cell **210** can convert light into electrical power. In various implementations, the PV cell **210** can include solar cells. The PV cell **210** can include a single or a multiple layer p-n junction and may be formed of silicon, amorphous silicon or other semiconductor materials such as Cadmium telluride. In some implementations, PV cell **210** can include photo-electrochemical cells. Polymer or nanotechnology may be used to fabricate the PV cell **210**. In various implementations, PV cell **210** can include multispectrum layers, each multispectrum layer having a thickness between approximately 1 μm to approximately 250 μm. The multispectrum layers can further include nanocrystals dispersed in polymers. Several multispectrum layers can be stacked to increase efficiency of the PV cell **210**.

[0043] The focusing plate **201** and/or the light guide **205** may be formed as a plate, sheet or film. In various implementations, the focusing plate **201** and/or the light guide **205** may be fabricated from a rigid or a semi-rigid material or a flexible material. In various implementations, the focusing plate **201** and/or the light guide **205** can have a thickness of approximately 1-10 mm. In some implementations, the overall thickness of the light collector **200** can be less than approximately 4-8 inches.

[0044] The focusing plate **201** includes a substrate having a forward surface that receives incident light and a rearward surface through which light propagates out of the focusing plate **201**. In the implementation illustrated in FIG. **2**A, the plurality of lenses **204***a*-**204***c* are disposed on the forward surface of the focusing plate **201**. However, in other implementations, the plurality of lenses **204***a*-**204***c* can be disposed on the rearward surface of the focusing plate **201**. In some implementations, the plurality of lenses **204***a*-**204***c* can be formed on the forward or rearward surface of the focusing plate **201**. In some implementations, a film, a layer or a plate provided with the plurality of lenses **204***a*-**204***c* can be adhered, attached or laminated to the forward or rearward surface of the focusing plate **201**. In various other implementations, the plurality of lenses **204***a*-**204***c* can be disposed through-out the volume of the focusing plate **201**. The plurality of lenses **204***a*-**204***c* can be formed by a variety of methods and processes, including lithography, etching, and embossing.

[0045] Each lens **204***a*, **204***b* and **204***c* has a curved surface S disposed about a cylinder axis **202**. The curved surface S has a transversal size D. The transversal size D can be between 0.1 mm and 15 mm. The curved surface S can have a circular, elliptical or a parabolic cross-section. In various implementations, the curved surface S can have an aspheric cross-section. Each lens **204***a*, **204***b* and **204***c* includes an optical axis **203** and is characterized by a focal length F that depends on the curvature and the transversal size D of the curved surface S. The focal length F can be between 3 mm and 80 mm. In some implementations, the lenses **204***a*-**204***c* can have the same transversal size D and/or focal length F. However, in other implementations, the transversal size D and/or the focal length F for each of the lenses **204***a*-**204***c* can be different. The distance between the plurality of lenses **204***a*-**204***c* and the bottom surface of the focusing plate **201** can be less than the focal length F such that ambient light focused by the plurality of lenses **204***a*-**204***c* is directed out of the focusing plate **201**.

[0046] In FIG. **2**A, the lenses **204***a*, **204***b* and **204***c* are spaced apart from each other by a gap. For example, in FIG. **2**A the optical axes of lenses **204***a* and **204***b* are spaced apart by a first spacing distance L**1** and the optical axes of lenses **204***b* and **204***c* are spaced apart by a second spacing distance L**2**. In various implementations, the lenses **204***a*, **204***b* and **204***c* can be regularly spaced apart from adjacent lenses such that consecutive lenses are spaced apart by a uniform distance. For example, the first spacing distance L**1** is approximately equal to the second spacing distance between the optical axes of lenses **204***b* and **204***c*. In some implementations, the lenses **204***a*, **204***b* and **204***c* can be irregularly spaced apart from adjacent lenses such that consecutive lenses are spaced apart by a non-uniform distance. For example, the first spacing distance L**1** between is greater than or less than the second spacing distance L**2**. Implementations including irregularly spaced apart lenses **204***a*-**204***c* can be advantageous to reduce Moiré fringes. In other implementations having more than three lenses, the first spacing distance L**1** can be the same for at least two pairs of adjacent lenses. In various implementations, the first spacing distance and the second spacing distance can be between 0.1 mm and 25 mm. In some implementations, the first spacing distance L**1** and/or the second spacing distance L**2** can be greater than or less than the transversal size D. In various implementations, adjacent lenses **204***a*, **204***b* and **204***c* can abut each other such that the distance between the optical axes of adjacent lenses **204***a*, **204***b* and **204***c* is equal to the transversal size D. The spacing between adjacent lenses **204***a*, **204***b* and **204***c* can be selected during manufacturing to vary the light collection efficiency and the transmissivity of the focusing plate **201**. For example, when the spacing between adjacent lenses **204***a*, **204***b* and **204***c* is reduced, the light collection efficiency is increased while the transmissivity of the focusing plate is decreased. Conversely, when the spacing between adjacent lenses **204***a*, **204***b* and **204***c* is increased, the light collection efficiency is decreased while the transmissivity of the focusing plate is increased.

[0047] The light guide **205** has a forward surface which receives incident light and a rearward surface opposite the forward surface through which light is transmitted out of the light guide **205**. The forward surface of the light guide **205** is closer to the focusing plate **201**. In various implementations, the forward surface of the light guide **205** can be adjacent or in contact with the rearward surface of the focusing plate **201**. In the illustrated implementations, the plurality of redirecting features **207** are disposed on or over the rearward surface of the light guide **205**, and protrude into the light guide **205** from the back surface. However, in other implementations, the plurality of redirecting features **207** can be disposed on or over the forward surface of the light guide **205**. In other implementations, the plurality of redirecting features **207** can extend into the bottom surface of the light guide **205**. The plurality of light redirecting features **207** can be manufactured using methods such as lithography, etching, imprinting, embossing, etc. In some implementations, the plurality of light redirecting features **207** can be provided on a film, a layer or a plate that is adhered, laminated or attached to the forward or rearward surface of the light guide **205**.

[0048] In the illustrated implementation, the plurality of redirecting features **207** are linear v-grooves that extend into the light guide **205**. However, in other implementations, the plurality of redirecting features **207** can be optical refracting, reflecting, diffracting or scattering features. In various implementations, the plurality of redirecting features **207** can include v-grooves having non-linear extent. For example, the axis of the v-grooves may be curved (e.g., circular or elliptical). V-grooves having non-linear extent may be advantageous to collect diffused ambient light, for example, under cloudy conditions. V-grooves arranged along curved paths may be also advantageous in focusing the ambient light. In various implementations, the side walls of V-grooves can be a generic quadratic curve, or a portion of a quadratic curve. For example, the side walls can be i.e, elliptical, parabolic, hypobolic or other higher order aspheric curves. V-grooves with curved sidewalls can have optical power to focus and/or concentrate the ambient light. The non-linear turning surface has surface normal that is tilted with respect to a normal to the light guide to efficiently collect off-axis light. FIG. **2**B illustrates a cross-sectional view of a linear v-groove **207***a* including planar facets **S1** and **S2** arranged at an angle θ with respect to each other. The angle between the planar facets can be between approximately 20 degrees and approximately 150 degrees. In various implementations, each linear v-groove can include two or more turning features. The turning features can include prismatic features, diffractive features, refractive features, reflective features, scattering features, holographic features, etc. Each linear v-groove **207** can correspond to one of the focusing lenses **204***a*, **204***b* and **204***c*. In various implementations, each linear v-groove **207** can be registered with a corresponding lens **204***a*, **204***b*, and **204***c* such that the apex of each linear v-groove coincides or is vertically aligned (relative to the illustrated orientation in FIG. **2**A) with the optical axis **203** of the corresponding lens **204***a*, **204***b* and **204***c*. In various implementations, the apex of each linear v-groove **207***a*, **207***b*, and **207***c* can be offset from the optical axis **203** of the corresponding lens **204***a*, **204***b* and **204***c*. In some implementations, the offset distance can depend on the latitude of the geographical location where the light collector **200** is disposed. In various implementations, the offset distance can be between approximately 0.01 mm and 0.5 mm. In some implementations, two or more v-grooves can be vertically aligned with the optical axis **203** of one lens such that light focused by one half-cylinder shaped lens is incident on the two or more v-grooves and subsequently directed towards the PV cell **210** by the two or more v-grooves. The plurality of linear v-grooves **207***a*-**207***c* are oriented in the same longitudinal direction as the lenses **204***a*-**204***c*. The plurality of linear v-grooves **207***a*-**207***c* can have a depth dimension d that extends into the bottom surface of the light guide **205**. In various implementations, the depth dimension d of each linear v-groove can have a value between approximately 0.001 mm to approximately 3 mm. In various implementations, the apex of the grooves can be vertically offset by approximately 0.1 mm to 5 mm from the focus of the plurality of cylindrical lenses.

[0049] In FIG. **2**A, the plurality of redirecting features **207***a*, **207***b* and **207***c* are spaced apart from each other such that a region that is devoid of redirecting features is included between the plurality of redirecting features **207***a*-**207***c*. For example, in FIG. **2**A the redirecting features **207***a* and **207***b* are spaced apart by a first gap distance g**1** and the redirecting features **207***b* and **207***c* are spaced apart by a second gap distance g**2**. In various implementations, the plurality of redirecting features **207***a*, **207***b* and **207***c* can be regularly spaced apart from adjacent redirecting features such that consecutive redirecting features are spaced apart by a uniform distance. For example, the first gap distance g**1** can be approximately equal to the second gap distance g**2**. In some implementations, the redirecting features **207***a*, **207***b* and **207***c* can be irregularly spaced apart from adjacent redirecting features such that consecutive redirecting features are spaced apart by a non-uniform distance. In other words, the first gap distance g**1** can be greater than or less than the second gap distance g**2**. In various implementations, the first gap distance g**1** and the second gap distance g**2** can vary between approximately 0.1 mm and 25 mm. In various implementations, adjacent redirecting features **207***a*, **207***b* and **207***c* can be disposed to abut each other such that there is no gap between adjacent redirecting features **207***a*, **207***b* and **207***c*. The spacing between the plurality of redirecting features **207***a*, **207***b* and **207***c* can be selected to vary the light collection efficiency and the transmissivity of the light guide **205**. For example, when the spacing between adjacent redirecting features **207***a*, **207***b* and **207***c* is reduced, the transmissivity of the light guide **205** is decreased. Conversely, when the spacing between adjacent redirecting features **207***a*, **207***b* and **207***c* is increased, the transmissivity of the light guide **205** is increased. The spacing between adjacent redirecting features **207***a*, **207***b* and **207***c* can also affect the light guiding efficiency. For example, if the spacing between adjacent redirecting features **207***a*, **207***b* and **207***c* is decreased, light propagating through the light guide

205 can suffer scattering losses due to repeated interaction with the plurality of redirecting features, thereby, decreasing the light guiding efficiency.

[0050] Still referring to FIG. 2A, one or more PV cells **210** are arranged along one or more edges of the light collector **200**. In various implementations, there may be a gap **212** between the focusing plate **201** and the light guide **205**. In various implementations, the gap **212** may include a layer of material (e.g., air, nitrogen, argon, or a viscous material) having a refractive index lower than the refractive index of the material of the light guide **205**. In other implementations, the gap **212** can be wholly or partially devoid of material or substance, and can be a vacuum. The height of the gap **212** can vary between approximately 1 mm- and 50 (mm. In some implementations, the material of focusing plate **201** can have a lower refractive index than the material of the light guide **205** such that the gap **212** can be eliminated. In various other implementations, the gap **212** can include a layer of material having a refractive index that matches the refractive index of the focusing plate **201** to the refractive index of the light guide **205**.

[0051] The light collector **200** can be configured to efficiently collect sunlight at different times during the day, as further discussed below. FIGS. **2**C-**2**E illustrate cross-sectional views of the implementation illustrated in FIG. **2**A and depict the light collection at various times during the day. FIGS. **3**A-**3**C illustrate perspective views of a portion of the implementation illustrated in FIG. **2**A and depict the light collection at various times during the day. To efficiently collect sunlight at all times during the day the half-cylinder shaped lenses **204***a*, **204***b* and **204***c* can be positioned such that the array of lenses is arranged in a north-south orientation; that is, so the cylindrical axis of each lens is oriented generally along the east-west direction such that at noon on an equinox the rays of the sun are incident on the each of the lenses **204***a*, **204***b* and **204***c* along the optical axis **203** of each of the lenses **204***a*, **204***b* and **204***c*. On other days, the rays of the sun at noon time are incident on the lenses **204***a*, **204***b* and **204***c* from a direction that is at an angle (plus or minus) with respect to the optical axis **203** of each of the lenses **204***a*, **204***b* and **204***c*. The angle between the incident direction of sunlight at noon time and the optical axis **203** of each of the lenses **204***a*, **204***b* and **204***c* can depend on the latitude of the geographical location where the light collector is disposed and the time of the year. The lenses **204***a*, **204***b*, and **204***c* are designed and configured to focus the light on to a corresponding linear v-groove **207***a*, **207***b*, and **207***c* (which may collectively be referred to as linear v-grooves or grooves **207**) at all times of the day as shown in FIGS. **2**C-**2**E and **3**A-**3**C thus providing a focused beam of light in a position that corresponds with the diurnal relative movement of the sun. When implemented in a window device, the cylindrical axis of the half-cylinder shaped lenses is generally aligned along the same direction as the track of the sun's diurnal movement. This can advantageously allow the window device to collect light efficiently at various times during the day and year.

[0052] FIG. **2**C and FIG. **3**B illustrate an example of light collection by the light collector **200** at noon. At noon when the sun is highest overhead, the collector **200** can be positioned such that the sun's rays **215** are incident on the focusing plate **201** along a direction approximately parallel to the optical axis **203** of the lenses **204***a*, **204***b* and **204***c*. The lenses **204***a*, **204***b* and **204***c* focus the incident light **215** along a line which coincides with the corresponding linear v-groove **207***a* as shown in FIG. **3**B. The linear v-groove **207***a* redirects the focused light such that redirected light **225** (FIG. **2**C) propagates through the light guide **205** towards the PV cell **210**. FIG. **2**D and FIG. **3**A illustrate the light collection by the light collector **200** in the morning when the rays of the sun **218** are incident on the light collector **201** from the east and FIG. **2**E and FIG. **3**C illustrate the light collection by the light collection by the light collector **200** in the evening when the rays of the sun **221** are incident on the light collector **201** from the west.

[0053] With reference to FIGS. **2**C-**2**E and **3**A-**3**C, ambient light **215**, **218** and **221** incident on the focusing plate **201** are focused by the lenses **204***a*, **204***b* and **204***c* such that focused beams of light **220** (FIG. **2**C), **223** (FIG. **2**D) and **226** (FIG. **2**E) are directed onto a corresponding linear v-groove **207***a*, **207***b* and **207***c*. The linear v-grooves **207** are adapted to redirect the focused light so that the redirected beams of light **225** (FIG. **2**C), **228** (FIG. **2**D) and **231** (FIG. **2**E) propagate towards the PV cells **210** disposed along the edges of the light guide **205**.

[0054] Ambient light that enters the light collector **200**, but is not redirected by the plurality of light redirecting features (or linear groves) **207** may propagate through the light collector **200**. In various implementations, the density or fill factor of the half-cylinder shaped lenses **204***a*, **204***b*, and **204***c* is configured such that the amount of light transmitted through the light collector **200** may vary (for example, from 0% to 100% transmission). In some implementations, the light collector is configured such that the amount of transmitted light is between about 25% and 75%, for example, about a 40% or about a 50% transmission measured at a certain sun angle (for example, such that it is at a normal angle to the light collector orientation. In some implementations, there is one linear groove **207** corresponding to each lense **204**. In some implementations there are two or more linear grooves **207** corresponding to each lense. This may be done to take into account the "movement" of the focused beam (for example, focused beam **223** in FIG. **2**D) as a result of changes in the relative position of the sun and the light collector **200**. By configuring some portions of the light receiving surface of the focusing plate **201** to have fewer cylindrical lenses **204** (for example, such that there is a portion of the light receiving surface on the light collector **200** that is not part of a lens) and one of the linear grooves **207** is associated with each lens **204**, a greater amount of the incident light falling on the light collector **200** will be transmitted through the light collector **200** when compared to a configuration having no space between the lenses. In other words, light that is not subject to being focused by a lens **204** and redirected by a linear grove **207** can pass through the light collector **200**. In some implementations, the focusing lenses **204** allow for a transmission if 50% of the light when the light source is at a normal incident angle with respect to the light collector **200**.

[0055] In various implementations, the density or fill factor of the plurality of lenses **204***a*, **204***b*, and **204***c* and the plurality of light redirecting features **207***a*, **207***b*, and **207***c* can be selected to transmit a certain percentage of the ambient light incident on the light collector **200**, for example, in the range of approximately 20%-80% of the ambient light incident on the light collector **200**. In some non-limiting example implementations, the focusing lenses **204** and the light redirecting linear grooves **207** can be configured to transmit a certain amount of light (in relation to the amount of light that enters the light collector **200**), for example, approximately 20-30%, 30-40%, 40-50%, 50-60%, 60-70%, or 70-80% of the ambient light incident on the light collector **200** by changing one or more characteristics of either or both of the focusing lenses **204** and the linear grooves **207**. For example, the size of the focusing lenses **204** (for example, diameter), the size of the linear grooves **207** (e.g., facet height, area of the facet surface exposed to the focused light beam), density of the focusing lenses **204**, and/or the size of a focused beam of light.

[0056] FIGS. **4**A and **4**B illustrate two different implementations of the light collector **200** illustrated in FIG. **2**A, each implementation having varying density or fill factor of the half-cylinder shaped lenses and the plurality of redirecting features. The implementation illustrated in FIG. **4**A has a higher density of fill factor of the lenses **204***a*-**204***c* and the plurality of redirecting features **207***a*-**207***c* as compared to the implementation illustrated in FIG. **4**B. Accordingly, the implementation illustrated in FIG. **4**B will transmit more received ambient light than the implementation shown in FIG. **4**A. In various implementations, some of the plurality of redirecting features **207***a*-**207***c* corresponding with one or more lenses **204***a*-**204***c* may be omitted to vary the amount transmitted through the light collector **200**. In various implementations, the height of the gap **212** between the focusing plate **201** and the light guide **205** can be varied to change the amount of light transmitted through the light collector **200**.

[0057] In various implementations, thin films having reflecting, diffracting or scattering features can be disposed forward or rearward of the focusing plate **201** and/or the light guide **205**. The thin films can be used to increase the light collection efficiency, provide visual effects, increase or decrease transmission or to provide other optical function.

[0058] The various implementations, described in FIGS. **2**A-**4**B can thus be used as power generating windows which can collect light efficiently at various times during the day. In various implementations, the power generating window including the light collecting structure can have varying degrees of transmissivity.

[0059] In various implementations, a PV power generating window including the implementations of the light collector **200** illustrated in FIGS. **2**A-**4**B can be obtained by assembling the focusing plate **201**, the light guide **205** and the PV cells **210** in a frame including electrical connections. In various implementations, the electrical connection may be embedded in the light guide **204**. Implementations of a PV power generating window including the implementations of the light collector **200** illustrated in FIGS. **2**A-**4**B can provide an aesthetically pleasing appearance, can efficiently collect and divert light to the PV cell at various times during the day and have a varying degree of transmissivity. In various implementations, implementations of a PV power generating window including the implementations of the light collector **200** illustrated in FIGS. **2**A-**4**B can have a visual effect comparable to or better than a window screen.

[0060] The light diverting efficiency of light collectors (in other words, the amount of light diverted towards the PV cell **210** by the light collector **200** illustrated in FIG. **2**A) can depend on the angle of incidence θ of the ambient light, the solar elevation and azimuth angles due to the sun's apparent movements through the sky from morning to evening due to earth's rotation and shifts from north to south in the northern hemisphere due to the earths revolution. For example, in some implementations, ambient light that is incident in a certain fixed range of angles can be efficiently collected and diverted towards the PV cell **210** by the light collector **200** and the light diversion efficiency decreases when light is incident at other angles outside the fixed range. The variation of the light collection efficiency on the incident angle is depicted in FIG. **5**B which illustrates the simulated optical efficiency (i.e., light diverting efficiency) as a function of the incidence angle.

[0061] For the purpose of simulation, an implementation of the light collector **200** is considered to be located at the equator as shown in FIG. **5**A. The equatorial plane is represented by the x-y plane. The simulated implementation includes cylindrical lens array including a plurality of half-cylinder shaped lenses having a radius of curvature of approximately 10 mm, focal length of approximately 19 mm. The adjacent lenses of the cylindrical lens array are spaced apart by a distance of approximately 7.9 mm. For simulation purposes, the v-grooves are assumed to have an apex angle of about 90 degrees, a height of about 2 mm. The consecutive v-grooves are spaced apart by a distance of about 7.9 mm. The v-grooves are disposed such that the plurality of light redirecting features is aligned along the y-axis, which represents the east-west direction. With reference to the implementation illustrated in FIG. **5**A, the track of the sun moves along a path from A→C→E in the x-z plane from winter to summer. During the day, the sun moves along a path from B→C→D in y-z plane.

[0062] FIG. **5**B illustrates the simulated optical efficiency (i.e., light diverting efficiency) as a function of the incidence angle for implementation illustrated in FIG. **5**A. The light diverting efficiency versus the angle of incidence of the ambient sunlight with respect to z-axis as the sun moves across the sky along a path from B→C→D during the day is shown by curve **315** in FIG. **5**B. Curve **315** represents the light diverting efficiency calculated at 12:00 pm every day for the entire year. The light diverting efficiency versus the angle of incidence of the ambient sunlight with respect to z-axis as the sun moves across the sky along a path from A→C→E during the year is shown by curve **320** in FIG. **5**B. Curve **320** is the light diverting efficiency for a specific day of the year when sun is at point C for the entire day. Curves **315** and **320** represent the decomposed performance from two distinct incident direction. In general, the solar performance will be a combination of the performance **315** and **320** depending on the location of the sun.

[0063] It is observed from curve **315** that the light collection efficiency decreases gradually from a peak value of about 76% as θ varies from 0 degrees to about 23 degrees beyond which it decreases sharply. If the light collector were located at a different place on earth located above or below the equator, the peak will shift to an angle of incidence that is equal to the latitude of the place ±23 degrees. It is observed from curve **320** that the light collection efficiency has a peak value of about 76% at θ of about 0 degrees and a second peak value of about 25% at θ of about 23 degrees. If the light collector were located at a different place on earth located above or below the equator, the first peak will occur at an incident angle that is equal to the latitude of the place and the second peak will occur at an incident angle that is equal to the latitude of the place ±23 degrees.

[0064] The size of the plurality of light redirecting features **110** and the spacing between consecutive light redirecting features can affect the light guiding efficiency of the light collector **100**. For example, if the size of the plurality of redirecting features **110** and/or or the density of the plurality of redirecting features **110** is large, then light propagating within the light guide **101** can strike the plurality of redirecting features **110** and be scattered out of the light guide **101**. The light collecting efficiency of the collector **100** can be reduced in this manner. In order to reduce scattering loss during propagation through the light guide **101**, the plurality of light redirecting features **110** can have a density between 0.1% and 10% of the area of the light guide, such that the light guide **101** includes regions that are devoid of the light redirecting features **110**. Additionally, in various implementations, the transverse size of the plurality of light redirecting features **110** can be between 0.1 mm and 5.0 mm and the height of the plurality of light redirecting features **110** can be between 0.1 mm and 1.0 mm such that light is efficiently collected without being scattered out of the light guide **205**. However, reducing the size of the plurality of light redirecting features **110** can reduce the area over which incident light focused by the array of focusing elements **114** is turned and efficiently guided by the light guide **101**. For example, light that is incident on the light collector **100** at different angles is focused by each focusing element in the array of focusing elements **114** to different spatial positions in the plane of the light guide **101**. Depending on the size, density and the position of the plurality of light redirecting features **110**, light incident in a certain angular range is focused on the plurality of light redirecting features **110** while light incident at other angles strikes a region of the light guide **101** that is devoid of light redirecting features **110**. Focused light that is not incident on a light redirecting feature is not turned and collected by the light guide **101** but instead exits out of the light guide **101**. Accordingly, the range of incidence angles over which the light collector **100** can efficiently collect light can depend on a variety of factors including but not limited to size of the plurality of light redirecting features **110**, density of the plurality of light redirecting features **110** and the with respect to the array of focusing elements **114**. For example, consider implementations, wherein each of the plurality of light redirecting feature is arranged below (or rearward of) a corresponding focusing element from the array of focusing elements **114**, such that the light redirecting feature is not offset with respect to the optical axis of the corresponding focusing element. In such implementations, light that is incident in an angular range of about 5-20 degrees with respect to a normal to the focusing plate **103** (or the optical axis of the focusing elements) can be efficiently collected and guided by the light guide **101**, while light incident at angles outside this angular range exits the light guide **101** and is not collected. This can affect the light collection efficiency of the light collector **100** as the incident sunlight changes direction from east to west through the day and as the direction of incident sunlight changes seasonally during the year. Implementations of light collectors described herein, including implementations **600** and **650** discussed below can increase the angular range over which incident sunlight is efficiently collected.

[0065] FIGS. **6**A and **6**B illustrate different implementations of a light collector including lenses and a plurality of light redirecting features, each implementation configured to collect light that is incident along a first direction that is normal to the light collector and a second direction that is oblique to the light collector. The implementation of the light collector **600** illustrated in FIG. **6**A includes a plurality of light guides **101***a*, **101***b* and **101***c* disposed below (or rearward of) the focusing plate **103**. In various implementations, the plurality of light guides **101***a*-**101***c* can include the same transmissive material. In other implementations, the plurality of light guides **101***a*-**101***c* can include different transmissive materials. As discussed above, the focusing plate **103** includes an array of focusing elements **114**. Each focusing element **114***a* in the array has an optical axis **603**. In various implementations, the optical axis **603** can be parallel to a normal to the surface of the focusing plate **103** on which the array of focusing elements **114** is disposed. In various implementations, the plurality of light guides **101***a*-**101***c* can be disposed with respect to the focusing plate **103** such that a gap **601** is included between the focusing plate **103** and the plurality of light guides **101***a*-**101***c*. In various implementations, the gap **601** can include a material having a refractive index that is lower than the material of the light guide **101***a* and the focusing plate **103**. One or more PV cells **105** can be disposed with respect to one or more edges of the plurality of light guides **101***a*-**101***c*.

[0066] Each of the plurality of light guides **101***a*, **101***b* and **101***c* includes a plurality of light redirecting features. For example, light guide **101***a* includes light redirecting features **110***a* and **110***b*; light guide **101***b* includes light redirecting features **110'***a* and **110'***b*; and light guide **101***c* includes light redirecting features **110"***a* and **110"***b*. The plurality of light redirecting features **110***a* and **110***b* in the first light guide **101***a* are disposed rearward of the plurality of focusing elements **114***a* and **114***b* in the array **114** such that each redirecting feature is aligned with the optical axis **603** of a corresponding focusing element. For example, the redirecting feature **110***a* is aligned with the optical axis of the focusing element **114***a* and the redirecting feature **110***b* is aligned with the optical axis of the focusing element **114***b*. The plurality of light redirecting features **110'***a* and **110'***b* in the second light guide **101***b* and the plurality of light redirecting features **110"***a* and **110"***b* in the third light guide **101***c* are disposed rearward of the plurality of focusing elements **114***a* and **114***b* in the array **114** such that redirecting features **110'***a*, **110'***b*, **110"***a* and **110"***b* are offset from the optical axis **603** of the corresponding focusing element **114***a* and **114***b*. In various implementations, the offset distance can be between 0.01 mm and about one-half the spacing between an adjacent focusing element. In some implementations, the offset distance can be between 0.01 mm and 0.5 mm.

[0067] In some implementations, a gap can be included between the light guide **101***a* and the light guide **101***b* and/or the light guide **101***b* and light guide **101***c*. In various implementations, the gap can include a material having an index of refraction lower than the refractive index of the material of the light guides **101***a*, **101***b* and **101***c*. The vertical distance between each of the plurality of light guides **101***a*-**101***c* and the focusing plate **103**, L**1**, L**2** and L**3**, can be selected such that plurality of light redirecting features **110***a*, **110***b*, **110'***a*, **110'***b*, **110"***a* and **110"***b* are within a distance Δf of the focal length f of each focusing element in the array **114**. In various implementations, Δf can be between about 1%-10% the focal length f. In various implementations, the vertical distance between the light guide **101***a* and the focusing plate **103**, L**1** can be between 1 mm and 10 mm. In various implementations, the vertical distance between the light guide **101***b* and the focusing plate **103**, L**2** can be between 1 mm and 20 mm. In various implementations, the vertical distance between the light guide **101***c* and the focusing plate **103**, L**3** can be between 1.0 mm and 30.0 mm.

[0068] Light that is incident on the plurality of focusing elements **114***a* and **114***b* at incident angles between approximately 0 degrees and approximately 60 degrees with respect to the optical axis **603** is focused by the focusing elements

114*a* and **114***b* toward the light redirecting features **110***a* and **110***b* that are aligned with the optical axis **603**. Light incident on the plurality of light redirecting features **110***a* and **110***b* is turned inward and guided within the light guide **101***a* toward the PV cells **105**. For example, in the illustrated implementation, ray of light **615** that is incident along a direction parallel to the optical axis **603** is focused toward the toward the light redirecting features **110***a* and **110***b* such that it is turned by the light redirecting features **110***a* and **110***b* and guided by total internal reflection in the first light guide **101***a*.

[0069] Light that is incident on the plurality of focusing elements **114***a* and **114***b* at oblique angles with respect to the optical axis **603** is focused by the focusing elements **114***a* and **114***b* toward the light redirecting features **110'***a*, **110'***b*, **110"***a* and **110"***b* that are offset from the optical axis **603**. In various implementations, light incident in the angular range between about 20 degrees and about 70 degrees with respect to the optical axis **603** can be focused toward the light redirecting features **110'***a*, **110'***b*, **110"***a* and **110"***b* such that it is guided in the second light guide **101***b* or the third light guide **101***c*. For example, ray **610** which is incident at an oblique angle between about 20 degrees and about 70 degrees with respect to the optical axis **603** is incident on the light redirecting feature **110'***a* and turned by the redirecting feature **110'***a* such that it is guided in the second light guide **101***b* by multiple total internal reflections toward the PV cell **105**. As another example, ray **612** which is incident at an oblique angle between about 20 degrees and about 70 degrees with respect to the optical axis **603** is incident on the light redirecting feature **110"***b* and turned by the redirecting feature **110"***b* such that it is guided in the third light guide **101***c* by multiple total internal reflections toward the PV cell **105**. In this manner the implementation **600** can be used to collect solar light that is incident in a wide range of angles (for example, between about 0 degrees and about 70 degrees with respect to the optical axis **603**).

[0070] The angular range over which incident light is collected can depend on various factors including but not limited to the focal length of the focusing elements in the array **114**, the size and the density of the plurality of light redirecting features **110***a*, **110***b*, **110'***a*, **110'***b*, **110"***a* and **110"***b*, the refractive indices of the material of the focusing plate **103** and the light guides **101***a*-**101***c*, the vertical distances, L**1**, L**2** and L**3** between the focusing plate **103** and the plurality of light guides **101***a*-**101***c*, etc. Based on the various factors, different implementations of the light collector **600** can be configured to collect light in an angular range between about 0 degrees and about 85 degrees with respect to the optical axis of the focusing elements with an efficiency of about 30% to about 60%. In various implementations, additional light guides can be disposed rearward of the light guide **101***c* to increase the angular range and/or the collection efficiency.

[0071] Although, in the illustrated implementation light guide **101***a* includes light redirecting features that are aligned with respect to the optical axis **603** and light guide **101***b* and **101***c* includes light redirecting features that are offset with respect to the optical axis **603**, in various implementations, each of the plurality of light guides **101***a*-**101***c* can include a first set of light redirecting features that are aligned with respect to the optical axis **603** and a second set of light redirecting features that are offset with respect to the optical axis **603**. In various implementations, each of the plurality of light guides **101***a*-**101***c* can include light redirecting features with different geometries and orientations so as to collect light efficiently in a wide range of angles.

[0072] FIG. 6B illustrates an implementation of a light collector **650** including a focusing plate **103** having an array of focusing elements **114** disposed on a forward (or upper) surface of the focusing plate and at least one light guide **101** including a plurality of light redirecting features **110***a* and **110***b*. The focusing plate **103** can include a plurality of turning features **605***a* and **605***b* that are disposed on a surface of the focusing plate opposite to the surface including the array of focusing elements **114**. Accordingly, in the illustrated implementation, the turning features **605***a* and **605***b* are disposed on the rearward (or lower) surface of the focusing plate **103**. In various implementations, the turning features **605***a* and **605***b* can be wedge shaped including a sloping surface **607** that subtends a wedge angle α respect to the rearward (or lower) surface of the focusing plate **103**. In various implementations, the wedge angle α can be between about 2-60 degrees. The turning features **605***a* and **605***b* can have a transverse size D3 that can be between 0.1 mm and 10.0 mm. The turning features **605***a* and **605***b* can be offset with respect to optical axis **603** of the corresponding focusing element as illustrated in the implementation **650**. In various implementations, the offset distance can be between 1.0 mm and 10.0 mm. In various implementations, the turning features **605***a* and **605***b* can be aligned with respect to the optical axis **603** of a corresponding focusing element such that light incident at oblique angles is focused by the focusing element toward the turning features **605***a* and **605***b*.

[0073] In various implementations, the plurality of light redirecting features **110***a* and **110***b* can be aligned with respect to the optical axis **603** of the corresponding focusing element in the array **114**, as illustrated. In some implementations, the plurality of light redirecting features **110***a* and **110***b* can be offset with respect to the optical axis **603** of the corresponding focusing element in the array **114**, as discussed above. The plurality of PV cells **105** is disposed along one or more edges of the light guide **101**. The light guide **101** can be separated from the focusing plate **103** by a gap **601**. In various implementations, the gap **601** can include a material having a refractive index lower than the refractive indices of the focusing plate **103** and the light guide **101**. The light guide **101** is disposed rearward of the focusing plate at a vertical distance of L**4**. In various implementations, the vertical distance, L**4**, can be selected such that plurality of light redirecting features **110***a*, and **110***b* are within a distance Δf of the focal length f of each focusing element in the array **114**. In various implementations, Δf can be between about 1%-10% the focal length f. In various implementations, the vertical distance between the light guide **101** and the focusing plate **103**, L3 can be between 1.0 mm and 10.0 mm.

[0074] In various implementations, the size, shape and position of the plurality of light redirecting features **110***a* and **110***b* can be configured such that light incident in the angular range between approximately 0 degrees and approximately 60 degrees with respect to the optical axis **603** is redirected by the redirecting features **110***a* and **110***b* and propagates by total internal reflection toward the PV cells **105**. For example, in the illustrated implementation, ray of light **615** that is incident along a direction parallel to the optical axis **603** is focused toward the toward the light redirecting features **110***a* and **110***b* such that it is turned by the light redirecting features **110***a* and **110***b* and guided by total internal reflection in the first light guide **101***a*.

[0075] Light that is incident on the array of focusing elements **114** at oblique angles with respect to the optical axis **603** is focused by the array of focusing elements **114** such that it is incident on the turning features **605***a* and **605***b* at an angle θ with respect to a normal to the sloping surface **607**. In various implementations, the angle θ can be in the range from about 30 degrees to about 80 degrees. Light incident on the turning features **605***a* and **605***b* is refracted out of the focusing plate **103** such that it is incident on a light redirecting feature **110***a* and **110***b*. The position and size of the turning features **605***a* and **605***b* is configured such that light that refracts out of the focusing plate **103** is redirected by the redirecting feature on which it is incident and guided within the light guide **101** toward the plurality of PV cells **105**.

[0076] For example, ray **625** which is incident at an oblique angle between about 20 degrees and about 70 degrees with respect to the optical axis **603** is refracted by the turning feature **605***a* such that it is incident on the light redirecting feature **110***a* and turned by the redirecting feature **110***a* into a guided mode of the light guide **101**. In this manner the implementation **650** can be used to collect solar light that is incident in a wide range of angles (for example, between about 0 degrees and about 70 degrees with respect to the optical axis **603**).

[0077] The angular range over which incident light is collected by the implementation **650** can depend on various factors including but not limited to the focal length of the focusing elements in the array **114**, the size and the density of the plurality of light redirecting features **110***a* and **110***b*, the refractive indices of the material of the focusing plate **103** and the light guide **101***a*, the size and the density of the turning features **605***a* and **605***b* and the refractive index of the material included in the gap **601** vertical distances. Based on the various factors, different implementations of the light collector **650** can be configured to collect light in an angular range between about 0 degrees and about 85 degrees with respect to the optical axis of the focusing elements with an efficiency of about 30% to about 60%. In various implementations, additional light guides can be disposed rearward of the light guide **101***a* to increase the angular range and/or the collection efficiency.

[0078] As discussed above, as the earth rotates, the incident angle of sunlight on an implementation of the light collector **100** will change and thus can affect the light diverting efficiency. FIGS. **7**A and **7**B illustrate the effect of a change in the incidence angle of sunlight due to the earth's rotation on the light diverting efficiency of an implementation of a light collector **100**.

[0079] When the sun is overhead, for example, in the noon, the sun light is incident at near normal angles on the array of focusing elements **114** of the light collector **100** and is focused on the plurality of light redirecting features **110** of the light guide **101** as illustrated in FIG. **7**A. As the position of the sun moves across the sky during the course of the day, the angle of incidence deviates from the normal direction with respect to the focusing elements and thus only a portion of the focused light is incident on the plurality of optical features **110** as illustrated in FIG. **7**B. Accordingly, the amount of incident radiation diverted towards the PV cell **105** can vary depending on the time of the day. In various implementations, it may be desirable to have light collectors **100** that can track and/or compensate for the diurnal movement of the sun to increase the amount of light diverted towards the PV cell **105**. The light collector implementations illustrated in FIGS. **2**A-**4**B are configured to efficiently collect and divert light that is received at different incident angles by the shape of the lenses **204***a*-**204***c*. Thus, the implementations illustrated in FIGS. **2**A-**4**B can be referred to as passively tracking or compensating for the diurnal movement of the position of the sun. The implementations of light collectors discussed below with reference to FIGS. **9**A-**10** are configured to efficiently collect and direct light that is received at different incident angles by mechanically moving different portions of the light collector **100** or **200**. Accordingly, the implementations discussed below with reference to FIGS. **9**A-**10** can be referred to as being able to actively track, or compensate for, the diurnal movement of the position of the sun.

[0080] To compensate for the movement of the sun relative to a fixed location on earth, either the focusing plate **103** (or the focusing plate **201**) or the light guide **101** (or the light guide **205**) can be moved horizontally or vertically, relative to each other, such that the focused light beam from the focusing lenses is incident on the plurality of light redirecting features **110** (or the plurality of light redirecting elements **207***a*-**207***c*). FIGS. **7**A**1**-**7**B**2** are simulation results showing the effect of the relative horizontal or vertical movement of different portions of an implementation of the light collector **100** illustrated in FIG. **1**. For the purpose of the simulation, an implementation of a light collector having a focusing plate **103** including an array of focusing elements **114** with 100% fill factor (for example, the entire surface area of the focusing plate **103** being covered by focusing elements **114**) was used.

[0081] FIGS. **8**A**1** and **8**A**2** illustrate the simulation results when sunlight is incident at an angle of about 32 degrees with respect to a normal to the forward surface of the focusing plate **103** and when each of the plurality of light redirecting features **110** is aligned with the optical axis of a corresponding focusing element in the array **114**. FIG. **8**A**2** is an expanded view of FIG. **8**A**1**. It can be observed from FIGS. **8**A**1** and **8**A**2** that most of the oblique incident rays focused by the array of focusing elements **114** are not directed onto the plurality of light redirecting features **110** and are thus not diverted towards the PV cell **105** disposed at the edges of the light guide **101**. Accordingly, the light diverting efficiency is substantially small (for example, the simulated light diverting efficiency is approximately 0.8% for the simulated implementation of FIGS. **8**A**1** and **8**A**2**).

[0082] FIGS. **8**B**1** and **8**B**2** illustrate the simulation results when sunlight is incident at an angle of about 32 degrees with respect to a normal to the forward surface of the focusing plate **103** and when the light guide **101** is horizontally moved by about 10 mm with respect to the focusing plate **103** such that each of the plurality of light redirecting features **110** is offset with respect to the optical axis of a corresponding focusing element in the array **114**. FIG. **8**B**2** is an expanded view of FIG. **8**B**1**. It is observed from FIGS. **8**B**1** and **8**B**2** that allowing for a lateral dislocation of about 10 mm results in the focused light striking the light redirectors. The simulated light diverting efficiency for the simulated implementation of FIGS. **8**B**1** and **8**B**2** is about 8%.

[0083] Considering these simulation results, various implementations where the focusing plate **103** (or the focusing plate **201**) and/or the light guide **101** (or the light guide **105**) can be moved either horizontally or vertically to change the distance or alignment between the focusing plate **103** (or the focusing plate **201**) and/or the light guide **101** (or the light guide **105**) can facilitate maintaining a more uniform light diverting efficiency through-out the day. Also, having a light collector that can move the focusing plate relative to the light guide vertically and/or horizontally allows some control over the amount of light that is transmitted through the solar collector.

[0084] FIGS. **9**A-**9**C illustrate different implementations of a light collector **900** including a focusing plate **103** and a light guide **101** that can be moved horizontally or vertically with respect to each other to maintain uniform light diverting efficiency through-out the day and/or to transmit a certain amount of incident light through the light collector **900**. As discussed above, horizontally moving the light guide **101** or the focusing plate **103** relative to each other can increase the light diverting efficiency by changing the horizontal position along the light guide **101** where the focused light from the focusing plate **103** strikes the light guide **101**. Vertically moving the light guide **101** or the focusing plate **103** relative to each other can increase the light diverting efficiency by changing the vertical position where the light from the focusing plate **103** is focused in the light guide **101**. The relative horizontal or vertical movement between the focusing plate **103** (or the focusing plate **201**) and the light guide **101** (or the light guide **105**) can be effected by one or more actuators **920***a*, **920***b* and **920***c*. The actuators **920***a*, **920***b* and **920***c* can be configured to horizontally or vertically move the light guide **101**, the focusing plate **103** or both to maintain uniform light diverting efficiency through-out the day and/or to transmit a certain amount of incident light through the light collector **900**. The actuators **920***a*-**920***c* can be adapted to displace the light guide **101** by a distance of approximately 0.01 mm-1 cm horizontally and vertically relative to the focusing plate **103**.

[0085] The implementation illustrated in FIG. **9**A is configured to horizontally and/or vertically move the light guide **101** relative to the focusing plate **103**. Actuators **920***a* and **920***b* are connected to the light guide **101** and can move the light guide **101** either alone or the light guide **101** and the PV cells **105***a* and **105***b* together along a vertical direction relative to the focusing plate **103**. Actuator **920***c* is connected to the light guide **101** and configured to move the light guide **101** either alone or the light guide **101** and the PV cells **105***a* and **105***b* together along a horizontal direction relative to the focusing plate **103**.

[0086] The implementation illustrated in FIG. **9**B is configured to vertically move the light guide **101** relative to the focusing plate **103** and horizontally move the focusing plate **103** relative to the light guide **101**. As discussed above, actuators **920***a* and **920***b* are connected to the light guide **101** and can move the light guide **101** either alone or the light guide **101** and the PV cells **105***a* and **105***b* together along a vertical direction relative to the focusing plate **103**. Actuator **920***c* is connected to the focusing plate **103** and configured to move the focusing plate **103** along a horizontal direction relative to the light guide **101**.

[0087] The implementation illustrated in FIG. **9**C is configured to horizontally and/or vertically move the focusing plate **103** relative to the light guide **101**. Actuators **920***a* and **920***b* are connected to the focusing plate **103** and can move the focusing plate **103** along a vertical direction relative to the light guide **101**. Actuator **920***c* is also connected to the focusing plate **103** and is configured to move the focusing plate **103** along a horizontal direction relative to the light guide **101**.

[0088] In various implementations, the actuators **920***a*, **920***b* and **920***c* can include a stepping motor and screw system, a linear electric motor, or a motor and gear system, a piezo-electric actuator, etc. In some implementations, the focusing plate **103** and the light guide **101** can be attached with leaf springs to allow relative movement.

[0089] FIG. **10** illustrates an implementation of a light collector **1000** that can actively track the movement of the sun across the sky. The implementation illustrated in FIG. **10** includes an optical element **1020** disposed between the focusing plate **103** and the light guide **101**. The optical element **1020** can include lenticular, prismatic, surface or volume refractive/diffractive features **1025** that can effect a change in the direction of the focused light exiting the focusing plate **103**. The optical element **1020** can be horizontally or vertically moved by actuators **920***a* and **920***c* such that the focused light strikes one of the plurality of light redirecting features **110** included in the light guide **101**. In some implementations, the diffractive element **1020** can be moved along with a movement in the focusing plate **103**, the light guide **101** or both. In various implementations, the optical element **1020** can effect a change in the distance where light is focused by the focusing plate **103**. This can be useful in accounting for the field curvature in those implementations where the locus of the focal point lies on a curve instead of a plane.

[0090] In various implementations described in FIGS. **9**A-**10**, the actuators **920***a*-**920***c* can be electrically controlled. In such implementations, the electrical output of the one or more PV cells **105** can be monitored to generate a control signal that can control the actuators **920***a*-**920***c*. The control signal can be generated by a feedback control element. For example, in some implementations, the movement of the focusing plate **103**, the light guide **101** or the diffractive element **1020** can be controlled such that the amount of light diverted to the one or more PV cell **105** (in other words, the electrical output of the PV cell **105**) is maximized. In some implementations, the amount of light transmitted through the light collectors **900** and **1000** can be monitored to generate a control signal that can control the actuators **920***a*-**920***c*. For example, the actuators **920***a*-**920***c* can be controlled such that the amount of light transmitted through the light collectors **900** and **1000** is maximized, minimized or maintained at a certain level. In various implementations, the actuators **920***a*-**920***c* can be controlled such that about 20%-80% of the incident ambient light is transmitted through the light collectors **900** and **1000**.

[0091] FIGS. **11**A and **11**B are flow charts illustrating two different examples of a method of manufacturing an implementation of a light collecting device similar to the implementations **100**, **200**, **600**, **650**, **900** and **1000** described above. Referring to FIG. **11**A, the method **1100** includes providing a cylindrical-lens array having half-cylinder shaped lenses as shown in block **1110**. The cylindrical-lens array can be similar to the focusing plate **201** discussed above. The cylindrical-lens array includes a top surface for receiving incident light and a bottom surface opposite the top surface. The half-cylinder-shaped lenses can be disposed on the top surface, the bottom surface or in the volume of the cylindrical-lens array. Each of the half-cylinder shaped lenses is characterized by a focal length F. The bottom surface of the cylindrical-lens array is disposed at a distance less than the focal length F such that the half-cylinder-shaped lenses directs light out of the bottom surface. In various implementations, the plurality of half-cylinder shaped lenses can be laterally spaced apart to define one or more lens spacings LS.

[0092] The method **1100** further includes disposing a light guide including a plurality of grooves as shown in block **1115**.

The light guide can be similar to the light guide **205** discussed above. The light guide has a top surface adjacent the bottom surface of the cylindrical-lens array and a bottom surface opposite the top surface of the light guide. The light guide includes a plurality of grooves oriented in the same longitudinal direction as the half-cylinder shaped lenses and disposed along the top surface or the bottom surface of the light guide. Each groove has a depth dimension that extends into the bottom surface of the light guide. Each groove defines at least one surface angled to redirect a portion of the focused light from the half-cylinder shaped lenses to one or more edges of the light guide. In various implementations, the plurality of grooves can be laterally spaced apart to define one or more groove spacings GS. The plurality of grooves is disposed at a distance D from the half-cylinder shaped lenses relative to a focal length of the half-cylinder shaped lenses. The lens spacings LS, the groove spacings GS and the distance D are selected such that about 20% to about 80% of light that enters the light collecting device is transmitted through the light collecting device and propagates out of the bottom surface of the light guide. The method **1000** further includes disposing at least one photocell along the one or more edges of the light guide as shown in block **1020**. In various implementations, the method **1100** can include providing a space between the cylindrical-lens array and the light guide as shown in block **1130**. The space can include a material having a refractive index lower than the refractive index of the light guide.

[0093] Referring to FIG. **11**B, the method **1150** includes providing a lens array having a plurality of focusing elements as shown in block **1155**. The lens array can be similar to the focusing plate **103** discussed above. The method **1150** further includes disposing a light guide including a plurality of light redirectors as shown in block **1160**. The light guide can be similar to the light guide **101** discussed above. The lens array is disposed such that ambient light is incident on the light collecting device is incident on a top surface of the lens array and is focused by the plurality of focusing elements on to the light guide. The method **1150** further includes disposing at least one photocell along the one or more edges of the light guide as shown in block **1165**. In various implementations, the method **1150** can include providing a space between the lens array and the light guide as shown in block **1170**. The space can include a material having a refractive index lower than the refractive index of the light guide. The method **1150** further includes providing at least one actuator coupled to the lens array or the light guide as shown in block **1175**. The actuator is configured to vertically or horizontally move the lens array or the light guide to change the position that light focused by the lens array is incident on the light guide.

[0094] Various implementations of light collectors described herein to efficiently collect, concentrate and direct light to a PV cell can be used to provide solar cells that have increased photovoltaic conversion efficiency. The light collectors can be relatively inexpensive, thin and lightweight compared to some conventional solar cells. The solar cells including light collectors described herein and coupled to one or more PV cells may be arranged to form panels of solar cells. Such panels of solar cells can be used in a variety of applications. For example, as described above, implementations of light collectors described herein coupled to one or more PV cells can be configured as building-integrated photovoltaic products such as, for example, windows, roofs, skylights, facades, etc. to generate electrical power. In other applications, implementations of light collectors described herein coupled to one or more PV cells may be mounted on automobiles and laptops to provide electrical power. Panels of solar cells including implementations of light collectors described herein coupled to one or more PV cells may be mounted on various transportation vehicles, such as aircrafts, trucks, trains, bicycles, boats, etc. Panels of solar cells including implementations of light collectors described herein coupled to one or more PV cells may be mounted on satellites and spacecrafts as well. Implementations of light collectors described herein coupled to one or more PV cells may be attached to articles of clothing or shoes.

[0095] Implementations of light collectors **100**, **200**, **600**, **650**, **800** and **900** discussed above including a plurality of focusing elements and a plurality of light redirecting features that are optically coupled to PV cells may have an added advantage of being modular. For example, depending on the design, the PV cells may be configured to be removably attached to the hybrid light collecting structures. Thus existing PV cells can be replaced periodically with newer and more efficient PV cells without having to replace the entire system. This ability to replace PV cells may reduce the cost of maintenance and upgrades substantially.

[0096] A wide variety of other variations are also possible. Films, layers, components, and/or elements may be added, removed, or rearranged. Additionally, processing operations may be added, removed, or reordered. Also, although the terms film and layer have been used herein, such terms as used herein include film stacks and multilayers. Such film stacks and multilayers may be adhered to other structures using adhesive or may be formed on other structures using deposition or in other manners.

[0097] Various modifications to the implementations described in this disclosure may be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other implementations without departing from the spirit or scope of this disclosure. Thus, the claims are not intended to be limited to the implementations shown herein, but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein. The word "exemplary" is used exclusively herein to mean "serving as an example, instance, or illustration." Any implementation described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other implementations. Additionally, a person having ordinary skill in the art will readily appreciate, the terms "upper" and "lower" are sometimes used for ease of describing the figures, and indicate relative positions corresponding to the orientation of the figure on a properly oriented page, and may not reflect the proper orientation of the device as implemented.

[0098] Certain features that are described in this specification in the context of separate implementations also can be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation also can be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination can in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination.

[0099] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flow diagram. However, other operations that are not depicted can be incorporated in the example processes that are schematically illustrated. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the illustrated operations. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described program components and systems can generally be integrated together in a single software product or packaged into multiple software products. Additionally, other implementations are within the scope of the following claims. In some cases, the actions recited in the claims can be performed in a different order and still achieve desirable results.

What is claimed is:

1. A light collecting device, comprising:

a cylindrical-lens array including a top surface for receiving incident light and a bottom surface opposite the top surface, the cylindrical-lens array having half-cylinder-shaped lenses aligned on the top surface to collect incident light, each of the half-cylinder-shaped lenses is characterized by a focal length F, the bottom surface of the cylindrical-lens array being disposed at a distance less than the focal length F such that the half-cylinder-shaped lenses directs light out of the bottom surface; and

a light guide having a top surface adjacent the bottom surface of the cylindrical-lens array and a bottom surface opposite the top surface of the light guide, the light guide including a plurality of grooves oriented in the same longitudinal direction as the half-cylinder shaped lenses and disposed along the bottom surface of the light guide, each groove having a depth dimension that extends into the bottom surface of the light guide and each groove defining at least one surface angled to redirect a portion of the focused light from the half-cylinder shaped lenses to one or more edges of the light guide,

wherein the light collecting device is configured such that about 20% to about 80% of light that enters the top surface of the cylindrical-lens array propagates through the light collecting device and out of the bottom surface of the light guide.

2. The device of claim **1**, wherein the focal length F is between about 5 mm and about 20 mm.

3. The device of claim **1**, wherein the distance between two consecutive grooves is between about 2 mm and 40 mm.

4. The device of claim **1**, wherein a transverse size of each half-cylinder shaped lens is between about 2 mm and about 10 mm.

5. The light collecting device of claim **1**, further comprising at least one photovoltaic cell disposed along one or more edges of the light guide.

6. The light collector device of claim **1**, wherein at least two of the half-cylinder-shaped lenses are laterally spaced apart by a first spacing distance.

7. The light collector device of claim **6**, wherein at least two of the half-cylinder-shaped lenses are laterally spaced apart by a second spacing distance, the second spacing distance being different from the first spacing distance.

8. The light collector device of claim **7**, wherein the first spacing distance is between about 0.1 mm and 25 mm and the second spacing distance is between about 0.1 mm and 100 mm.

9. The light collector device of claim **6**, wherein the first spacing distance is the same for at least two pairs of adjacent half-cylinder shaped lenses in the cylindrical-lens array.

10. The light collector device of claim **6**, wherein the first spacing distance is between about 0.1 mm and 100 mm.

11. The light collector device of claim **6**, wherein the at least two half-cylinder-shaped lenses are characterized by a transversal size, wherein the first spacing distance is less than the transversal size.

12. The device of claim **1**, wherein each of the plurality of grooves is vertically aligned with a center portion of one of the half-cylinder shaped lens.

13. The device of claim **1**, wherein a set of at least two or more grooves are vertically aligned with a center portion of one of the half-cylinder shaped lenses such that light focused by the one half-cylinder shaped lens is incident on the at least two or more grooves and redirected by the at least two or more grooves towards the at least one photovoltaic cell.

14. The device of claim **1**, wherein the apex of the grooves are vertically offset by approximately 0.1 mm to 5 mm from the focus of the plurality of half-cylinder shaped lenses.

15. The device of claim **1**, wherein the plurality of grooves are spaced apart by a first gap of between about 0.1 mm and 200 mm.

16. The device of claim **1**, wherein a set of the plurality of grooves are offset with respect to an optical axis of corresponding half-cylinder shaped lenses.

17. The device of claim **1**, wherein at least two adjacent grooves are spaced apart by a first gap and at least two adjacent grooves are spaced apart by a second gap different from the first gap.

18. The device of claim **1**, wherein each of the plurality of grooves includes two or more turning features.

19. The device of claim **18**, wherein the turning features include at least one of: prismatic features, holographic features, diffractive features, refractive features, reflective features and scattering features.

20. The device of claim **1**, wherein each of the plurality of grooves includes two or more grooves.

21. The device of claim **1**, wherein the light guide has a refractive index characteristic greater than a refractive index of the cylindrical lens-array.

22. The device of claim **1**, further comprising a substance having a refractive index lower than a refractive index of the light guide, the substance sandwiched between cylindrical-lens array and the light guide.

23. The device of claim **1**, further comprising a gap between the light guide and the cylindrical-lens array.

24. The device of claim **23**, wherein an amount of light transmitted through the light collecting device can be selected by selecting a height of the gap.

25. The device of claim **1**, configured as a window of a building.

26. A light collecting device, comprising:

a plurality of means for focusing incident light configured in an array plate, each of focusing means characterized by a focal length F such that the focusing means half-directs light out of a bottom surface of the array plate; and

means for guiding light disposed adjacent to the bottom surface of the array plate, the light guiding means including means for redirecting light oriented in the same longitudinal direction as the focusing means and disposed along a bottom surface of the guiding means,

wherein the light collecting device is configured such that about 20% to about 80% of light that enters plurality of focusing means propagates through the light collecting device and out of the bottom surface of the light guiding means.

27. The light collecting device of claim **26**, further comprising at least one photovoltaic cell disposed along one or more edges of the light guiding means.

28. The light collecting device of claim **26**, wherein the plurality of focusing means includes a plurality of half-cylinder-shaped lenses.

29. The light collector device of claim **26**, wherein the light guiding means comprises a light guide having a top surface adjacent the bottom surface of the cylindrical-lens array and a bottom surface opposite the top surface of the light guide, and wherein the light redirecting means comprises a plurality of grooves oriented in the same longitudinal direction as the half-cylinder shaped lenses and disposed along the bottom surface of the light guide, each groove having a depth dimension that extends into the bottom surface of the light guide and each groove defining at least one surface angled to redirect a portion of the focused light from the half-cylinder shaped lenses to one or more edges of the light guide.

30. A method of manufacturing a light collecting device, the method comprising:

providing a cylindrical-lens array including a top surface for receiving incident light and a bottom surface opposite the top surface, the cylindrical-lens array having half-cylinder-shaped lenses aligned on the top surface to collect incident light, each of the half-cylinder-shaped lenses is characterized by a focal length F, the bottom surface of the cylindrical-lens array being disposed at a distance less than the focal length F such that the half-cylinder-shaped lenses directs light out of the bottom surface; and

disposing a light guide having a top surface adjacent the bottom surface of the cylindrical-lens array and a bottom surface opposite the top surface of the light guide, the light guide including a plurality of grooves oriented in the same longitudinal direction as the half-cylinder shaped lenses and disposed along the bottom surface of the light guide, each groove having a depth dimension that extends into the bottom surface of the light guide and each groove defining at least one surface angled to redirect a portion of the focused light from the half-cylinder shaped lenses to one or more edges of the light guide,

wherein the plurality of half-cylinder shaped lenses are disposed laterally spaced apart to define one or more lens spacings LS, the plurality of grooves are disposed laterally spaced apart to define one or more groove spacings GS, and the plurality of grooves are disposed at a distance D from the half-cylinder shaped lenses relative to a focal length of the half-cylinder shaped lenses, and the lens spacings LS, the groove spacings GS and the distance D are selected such that about 20% to about 80% of light that enters the light collecting device is transmitted through the light collecting device and propagates out of the bottom surface of the light guide.

31. The method of claim **30**, further comprising providing a space between the cylindrical-lens array and the light guide.

32. The method of claim **31**, further comprising providing a material having a lower refractive index than the refractive index of the light guide in the space.

33. The method of claim **30**, further comprising disposing at least one photovoltaic cell along one or more edges of the light guide.

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